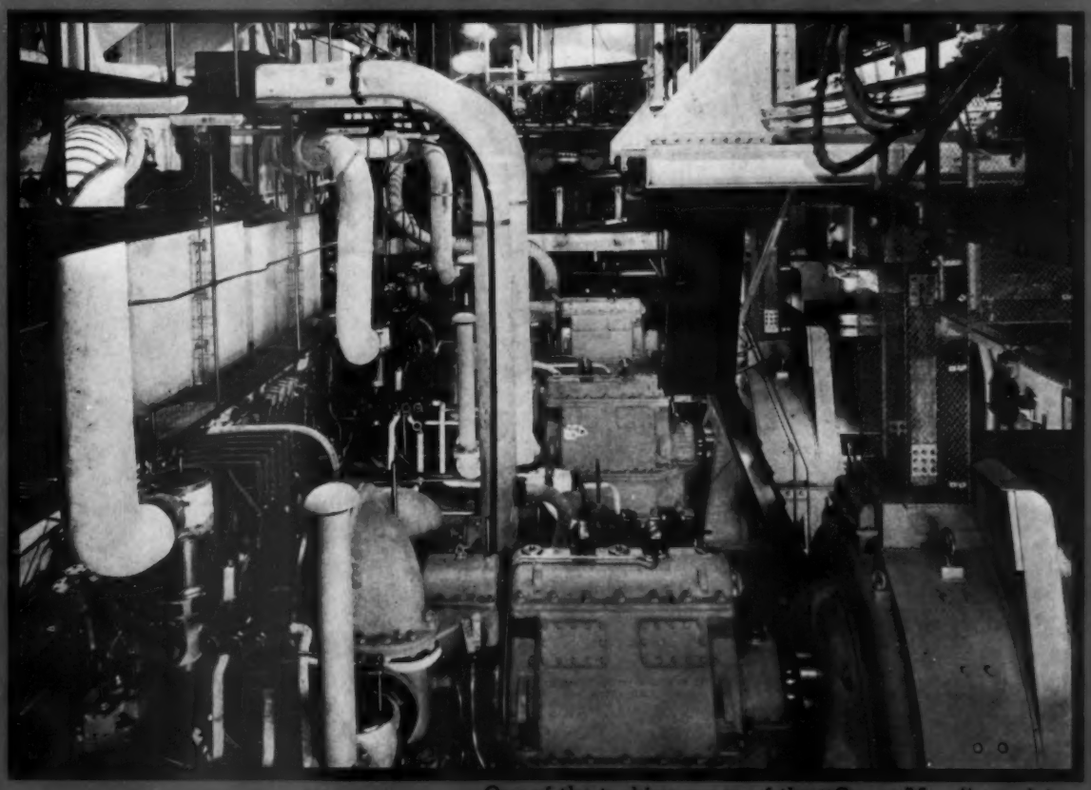
COMBUSTION

JUN 9

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 7, No. 12 JUNE, 1936 25c a copy



One of the turbine rooms of the "Queen Mary" supplying electricity for numerous services throughout the ship

Radiography as Applied to Welded Boiler Drums

Value of Proper Furnace Equipment to Power Plant Economy

Coordination of Boiler Auxiliaries

Significant . . .

of the trend in central station boiler buying are these projects awarded to COMBUSTION ENGINEERING

during the past seven months

***APPALACHIAN ELECTRIC POWER CO.,** *Logan, W. Va.*
One unit: capacity — 1,000,000 lb; design pressure — 1425 lb; total temperature — 925 F

***CONNECTICUT LIGHT & POWER CO.,** *Montville Station, Waterbury, Conn.*
Two units: capacity — 130,000 lb each; design pressure — 725 lb; total temperature — 825 F

DETROIT EDISON CO., *Conners Creek Station*
Two units: capacity — 392,000 lb each; design pressure — 710 lb; total temperature — 850 F

***KANSAS CITY POWER & LIGHT CO.,** *Northeast Station*
One unit: capacity — 300,000 lb; design pressure — 1400 lb; total temperature — 815 F

***MISSOURI POWER & LIGHT CO.,** *Jefferson City, Mo.*
One unit: capacity — 100,000 lb; design pressure — 900 lb; total temperature — 825 F

***NEBRASKA POWER CO.,** *Omaha Steam Station*
One unit: capacity — 275,000 lb; design pressure — 1350 lb; total temperature — 910 F

***NEW YORK EDISON CO.,** *Waterside No. 2 Plant*
Two units: capacity — 500,000 lb each; design pressure — 1400 lb; total temperature — 900 F

***ROCHESTER GAS & ELECTRIC CORP.,** *Station 3*
One unit: capacity — 250,000 lb; design pressure — 750 lb; total temperature — 750 F

***UNITED LIGHT & POWER ENGINEERING & CONSTRUCTION CO.**
Riverside Station, Davenport, Iowa
One unit: capacity — 225,000 lb; design pressure — 900 lb; total temperature — 825 F

***UTAH POWER & LIGHT CO.,** *Provo Steam Electric Station*
One unit: capacity — 200,000 lb; design pressure — 450 lb; total temperature — 760 F

***VIRGINIA ELECTRIC & POWER CO.,** *12th St. Station, Richmond, Va.*
One unit: capacity — 450,000 lb; design pressure — 925 lb; total temperature — 835 F

VIRGINIA PUBLIC SERVICE CO., *Alexandria, Va.*
One unit: capacity — 60,000 lb; design pressure — 725 lb; total temperature — 750 F

**Complete CE units — boiler, furnace, firing and in most cases heat recovery equipment.*

C-E

COMBUSTION ENGINEERING COMPANY, INC.

200 MADISON AVENUE, N. Y.

A-281

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SEVEN NUMBER TWELVE

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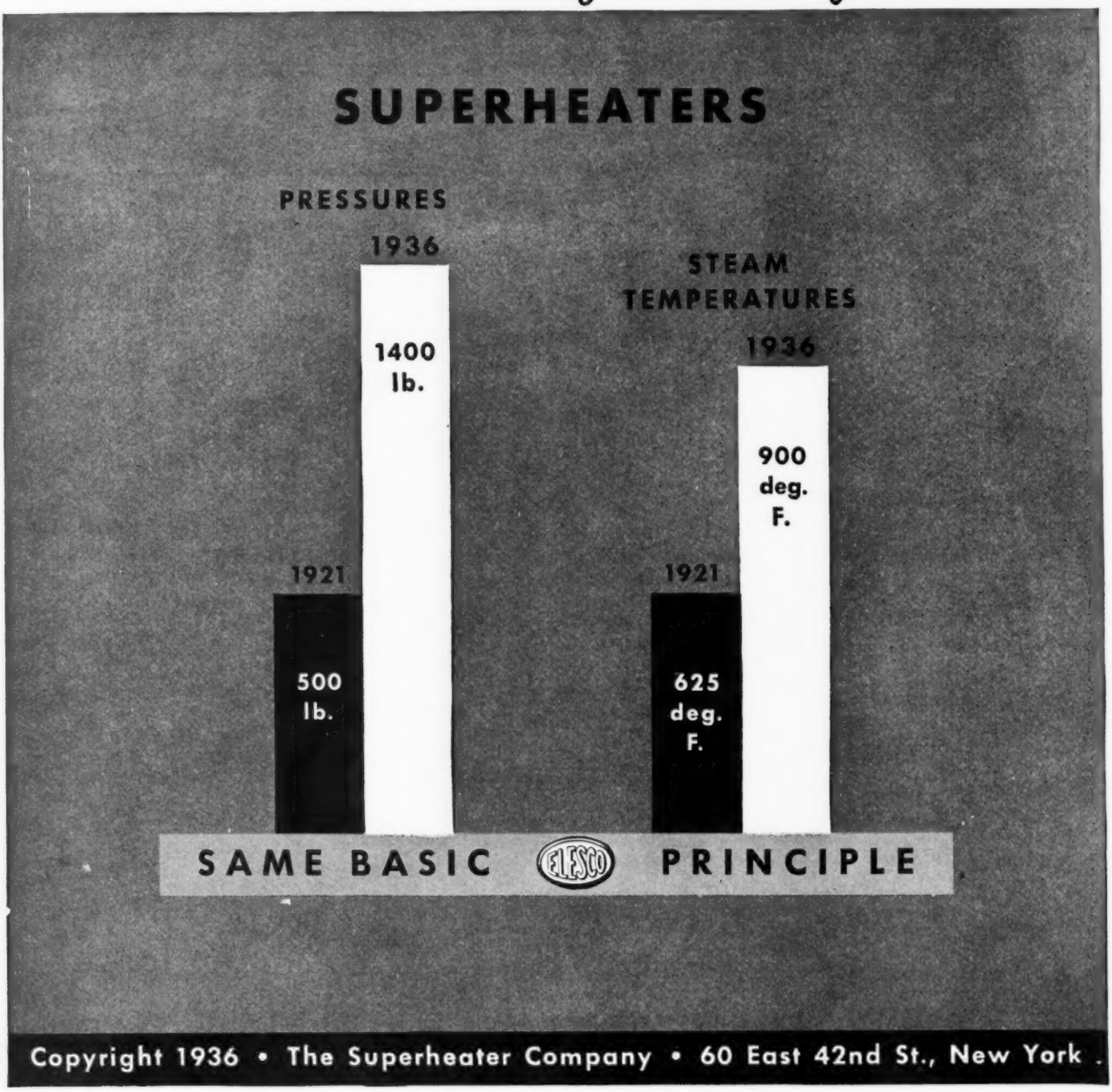
CCA

Focused Skill Begets Competence



Fundamentally correct principles of design . . . progressively refined to meet ever increasing duty and capacity requirements . . . contribute the element of stability required in your equipment purchases

ELESCO ELESCO SUPERHEATER ELESCO ECONOMIZER LJUNGSTROM AIR PREHEATER ORDINATED

Difficult Corrosion Problems

While infrequent, there are cases in which some of the best talent has failed in its efforts to correct the situation in hand. The following example is of this type:

In this instance Stirling type boilers having an integral economizer for each unit were in use. The boiler feed for this was a zeolited water carrying the following average totals:

1.75 ppm of hardness
5.00 ppm of precipitating solids
18.00 ppm of total alkalinity
45.00 ppm of total solids

The plant was equipped with an oversize heater and, according to the Winkler test, delivered water to the boilers with zero oxygen most of the time, and occasional maximum readings of 0.035 cc per liter. In addition to this, the pH of the feedwater was held in excess of 8.5; sodium sulphite was maintained in the blowdown water in excess of 200 ppm and boiler blowdown water was recirculated into the feedwater. The very best cooperation was extended on the part of the plant operators in holding to these standards, together with all the recommendations extended by the boiler, heater and softener manufacturers, who were directly interested in the performance of their respective equipments.

Regardless of this, corrosion continued over a period of two years in the lower drum and tubes of the integral economizers. Later, marked increases in the sulphite treatment also failed to prevent this.

After proper treatment adjustments the corrosion in this case was immediately arrested and then definitely corrected within four months. The first move in this readjustment was to increase the pH to 9.5. This increase failed to prevent the dissolving action of the zeolited water as it was measured by its effects on special steel test pieces located within the affected areas, and the pH was, therefore, increased to 10.5 and better, through the use of caustic soda. This was later supplemented by a lime treatment in sufficient quantities to satisfy the dissolving properties of the zeolite water and at the same time provide a protective coating over the corroding areas.

This was first introduced through the open heater, but the inhibiting effect of the high pH and high temperature water in the economizer prevented the lime reactions to the most desirable extent, with the result that this feed was changed to the cold-water supply tank before the heater.

The action of the sulphite was, also, improved through its continuous recirculation in the water space within the heater. This was brought about through the location of a circulating manifold on the outside of the heater having two suctions, one from each head end and one discharge into the water space through the center of the side. The circulations of the water through the manifold were induced by means of three live steam jets, one located centrally at the discharge and one each at the suction end. All chemical treatments and the recirculated blowdown waters were fed through this into the circulating waters.

Multiple benefits accrue from such an arrangement, because it—

(1) Provides a more intimate mixture of all additions with the feedwater before it is delivered to the boilers;

(2) Allows for longer contacts and resulting greater reactions of these additions with the constituents in the feedwater for the correction of which they are intended;

(3) Causes a scrubber action in the water and increases its temperature in the location within the heater where it proves most effective.

In reviewing this experience with others along the same line, there are certain inevitable conclusions. A few of these follow:

First:—The last trace of oxygen which the best deaerating heater equipments and operations do not remove is a potential source for trouble in some instances and requires the use of corrective agents, if corrosion is to be prevented with a definite certainty.

Second:—There is not enough practical difference in the chemical treatments for such purposes, whether the deaerated feedwater contains 0.1 or 0.001 cc per liter of oxygen, to penalize any plant for the much greater initial costs of the more effective deaerating heater types, because, as was stated above, treatments are essential for the best guarantees against corrosion, and dosing, under the circumstances, is nearly the same.

Third:—That the pH value of the feedwater must be high enough to maintain light depositions of protective coatings over the water-exposed metal surfaces.

Fourth:—That the addition of caustic lime under definite control proves an effective medium for providing such coatings and, also, neutralizes the dissolving properties of the water in use.

Fifth:—That the high pH and higher temperatures in the feedwaters retard the reaction of such lime additions, making it necessary to introduce them in the cold waters before the heater, especially where zeolited waters constitute the source of the boiler feed supply.

Sixth:—Where lime is required to give the necessary protective film over the affected areas and objectionable depositions take place within the steaming areas of the boiler, the use of proper colloids is necessary.

In concluding, let me say that the above proves that with the experience, facilities and definite methods in hand for checking results in the field, that there is no excuse today for permitting any corrosion conditions to continue, regardless of the severity and location of this.

Cyrus Wm. Rice, *President*

CYRUS Wm. RICE & CO., INC.
HIGHLAND BUILDING—PITTSBURGH, PA.

COPES SELECTED FOR CONNERS CREEK

NEW DOUBLE-END BENT-TUBE BOILERS EVAPORATE 330,000 POUNDS PER HOUR AT 710 POUNDS W.S.P. AND 825 DEGREES

MODERN *feed control for the modern Boiler Plant*

The modernization program at the Conners Creek Station of the Detroit Edison Company was based on intelligent planning and sound engineering. Equipment was purchased on the basis of proven performance and dependability . . . the lowest ultimate cost.

All new boilers are equipped with COPES Feed Water Regulators. The valves . . . especially designed for the operating conditions . . . are mounted above the tension type thermostats.

Let COPES engineers help you modernize. Have them design a system of boiler feed control for your individual needs. Depending on your operating conditions, regulation will be from water level or steam flow—with or without differential pressure control—with accurate, rugged and absolutely dependable equipment. Write for further information.

NORTHERN EQUIPMENT COMPANY
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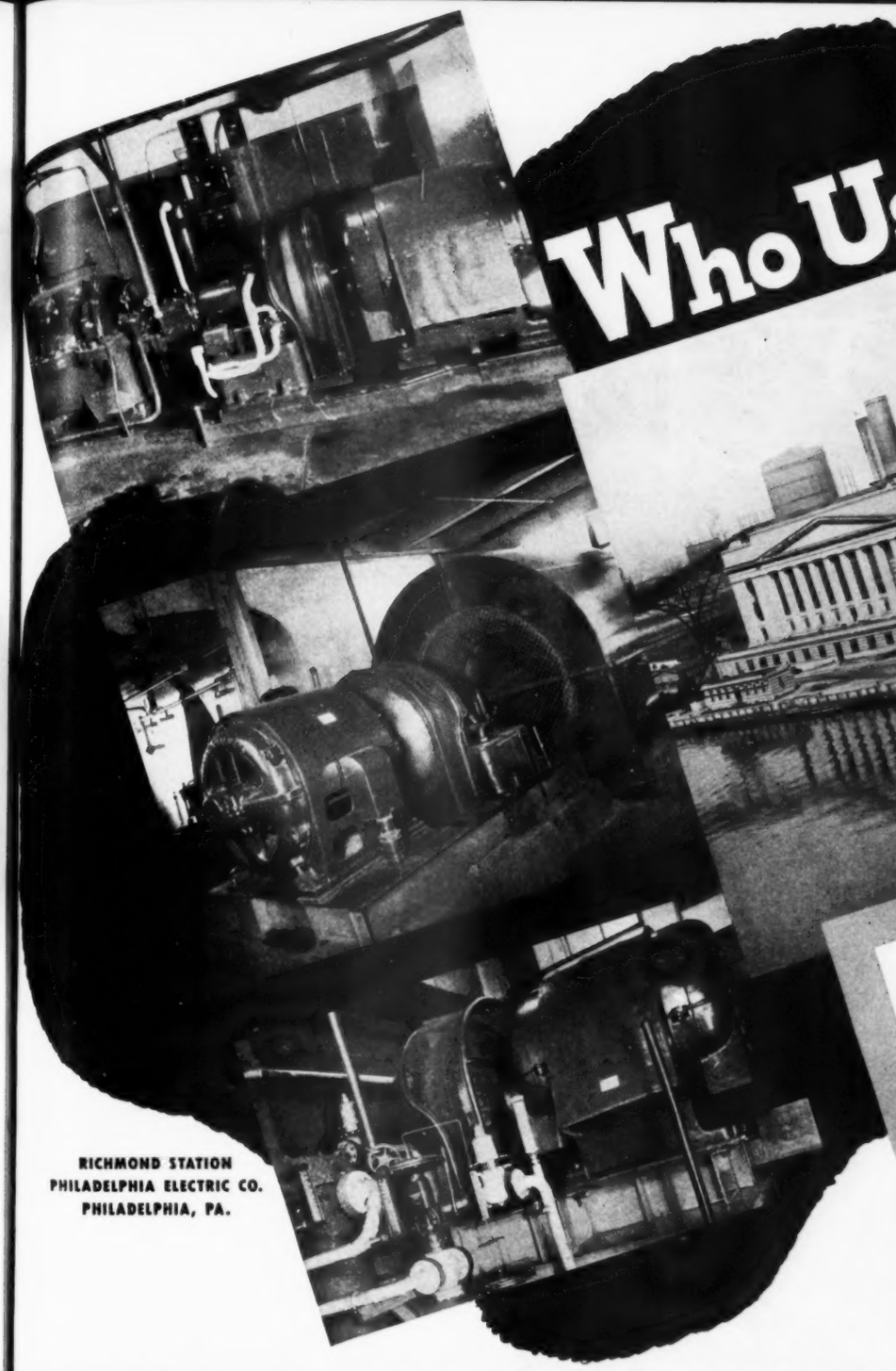
COPES Feed Water Regulators, Differential Valves, Pump Governors, Balanced Valves, Float Valves, Motor Valves. Thrustor Valves, Liquid Level and Drainage Controls, Fuel Cut-Off Valves, Valve Movement Indicators.

COPES
SYSTEM OF BOILER FEED CONTROL

Who Uses Them?



RICHMOND STATION
PHILADELPHIA ELECTRIC CO.
PHILADELPHIA, PA.

Here's a Partial List of Other Users

POTOMAC ELECTRIC POWER CO.
Buzzard's Point Station

KANSAS CITY POWER & LIGHT CO.
Kansas City, Mo.

PENNSYLVANIA RAILROAD CO.
Philadelphia, Pa.

HERSHEY CHOCOLATE CO.
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GARDNER-RICHARDSON CO.
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CONSOLIDATED MINING AND SMELTING CO.
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Springfield, Ill.

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Decatur, Ill.

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ELIZABETH HO
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PHILADELPHIA ELECTRIC USES HYDRAULIC COUPLINGS FOR VARIABLE SPEED, FAN AND PUMP DRIVE. Ten automatically controlled Hydraulic Couplings are used to drive eight large mechanical draft fans and two condensate pumps at variable speed from constant-speed motors at the Richmond Station of the Philadelphia Electric Company. This order was placed after a seven-month test conducted by the buyer under actual operating conditions during which time Hydraulic Coupling drive proved to be the most efficient means of adjusting fan and pump loads to the steam requirement of the boilers. The Richmond Station totaling 5,600 coupling horsepower is but one of many applications where a wide range of speed control is required, and Hydraulic Couplings have been selected for variable speed operation from constant speed motors. Write for a complete Case History of this installation, or any other installation listed.

HYDRAULIC COUPLING DIVISION

632 FISHER BUILDING
DETROIT, MICH.

40 WEST 40TH STREET
NEW YORK, N. Y.

AMERICAN BLOWER CORPORATION

again...

ELECTRUNITE BOILER TUBES LEAD THE FIELD

ELECTRUNITE
REG. U.S. PAT. OFF.
STEEL & TUBES ELECTRIC WELD
BOILER TUBES

THE NORMALIZED TUBES WITH THE SCALE-FREE SURFACE

An outstanding contribution to the improvement of boiler tubes made possible by the latest-type controlled atmosphere bright annealing furnace.

Not so many years ago, Steel and Tubes, Inc., announced a new and modern type of boiler tube —ELECTRUNITE—possessing many features not attained commercially in any other type of tube. That industry quickly realized the advantages of this tube is attested by the thousands and thousands of tubes installed and giving safe, trouble-free, economical service today.

During this time, many further improvements have been made in ELECTRUNITE Boiler Tubes. Steel and Tubes engineers, not satisfied even with the best, are continually seeking new processes or new methods that will provide industry with even better tubes.

Now, Steel and Tubes announces a new development—an outstanding contribution to the improvement of boiler tubes—a tube normalized at a temperature above 1650° F. without producing scale or in any way disturbing the fine surface of the original cold-worked tubing.

Pickled flat-rolled steel, absolutely scale-free and with a surface further improved by cold working during the forming of the tube, is passed through the latest type controlled atmosphere electric bright annealing furnace. Because the furnace temperature is accurately controlled, there is never any danger, regardless of how heavy the gauge, of crystallization of the metal, and thus accurate control of grain size is insured.

The resulting tube is entirely free from scale, inside and outside. The bright surface resulting is an aid to inspection, as defects cannot be concealed—thus making ELECTRUNITE Boiler Tubes the safest tubes that can be installed. Add the advantage of the controlled atmosphere normalizing to these features—uniformity of diameter; uniformity of wall thickness rarely varying more than .003 in. at any cross-section; a weld as strong as the wall; freedom from inside scabs, slivers, seams, etc.—and the real value of this improved ELECTRUNITE Boiler Tube is quickly apparent.

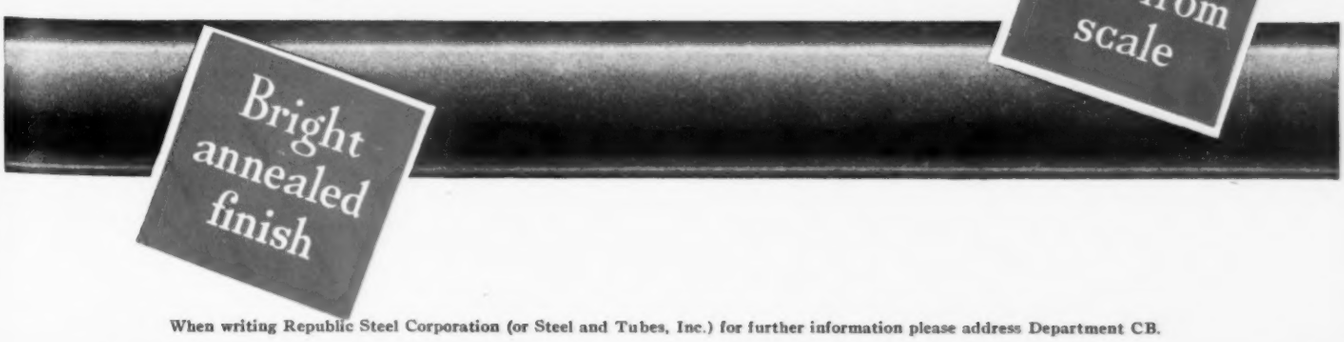
Would like to know more about ELECTRUNITE? Write us for complete detailed information.

Steel and Tubes *Inc.*

WORLD'S LARGEST PRODUCER OF ELECTRICALLY WELDED TUBING

CLEVELAND . . . OHIO

SUBSIDIARY OF REPUBLIC STEEL CORPORATION



When writing Republic Steel Corporation (or Steel and Tubes, Inc.) for further information please address Department CB.

Inseparable as

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Willard Storage Battery Co., Cleveland, O.
Firestone Tire & Rubber Co., Akron, Ohio
Goodyear Tire & Rubber Co., Akron, Ohio
National Tube Co., Lorain, Ohio
Standard Oil Co. of Ohio, Plant No. 1, Cleveland, Ohio
Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich.
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Yale & Towne Mfg. Co., Stamford, Conn.
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Carnegie-Illinois Steel Co., Carrie Furnaces, Rankin, Pa.
Large Distilling Co., Large, Pa.
Spang, Chalfant Co., Ambridge, Pa.
Weirton Steel Co., Weirton, W. Va.
Duquesne Light Co., Colfax Sta., Springdale, Pa.
Jones & Laughlin Steel Corp., Aliquippa, Pa.
Mesta Machine Co., Homestead, Pa.
National Tube Co., Ellwood City, Pa.
Pittsburgh Steel Co., Monessen, Pa.
West Penn Power Co., Springdale, Pa.
Titanium Pigment Co., St. Louis, Mo.

AUTOMATIC COMBUSTION CONTROL . . . . .

Hagan-Hall

the two sides of a coin

55 L

How many words has a dictionary? Fifty thousand? Two hundred thousand? What difference does it make? Knowing *all* the words wouldn't make a playwright. Nor does mere mechanical equipment, however fine and rugged, take the place of engineering brains . . . or a smattering of chemistry equal thorough chemical resourcefulness.

Steam plants have two closely related problems—control of combustion, and conditioning of the boiler water. Modern high pressures make both problems acute. Operating costs will be high or low—steaming results good or bad—depending on how these are solved.

In the low-cost maintenance of steam power, correct automatic fuel-air combustion control is irretrievably linked with the chemical control of the boiler water. The two are as interdependent, as inseparable, as the two sides of a coin. They are a single problem calling for *dual* experience and a *dual* solution.

The heart of a control system that will fit all variables into a unified "pattern of power and safety" is the designing and engineering experience put into it by *men.* Not valves and dampers and fans and governors.

The generation of billions of pounds of steam—without turbining, blistered tubes and costly outage—rests on chemical knowledge and organization, but it still is a question of men and experience.

No other organization in the world has won such high recognition in both related fields.

HAGAN CORPORATION
PITTSBURGH, PENNA.

HALL LABORATORIES, INC. THE BUROMIN COMPANY

SCIENTIFIC BOILER WATER CONDITIONING

Dual Service

Cut Costs with J & L SEAMLESS STEEL BOILER TUBES

You save the most money when you use materials that are economical to work during installation and that will give maximum satisfactory service. You can depend on J & L hot rolled seamless steel boiler tubes to bring you this important combination of money-saving advantages because of these three principal factors in manufacturing:

1. Jones & Laughlin produces its own steel and uses for J & L boiler tubes only the best steel for the purpose.

2. J & L tubes are made by an exclusive process in which the solid billet is formed into a tube by a series of forging operations. Each step in manufacture increases the ductility of the steel and adds to the uniform strength and dependability of the finished product. Due to their greater ductility, J & L tubes can be formed, expanded and beaded in cold with remarkable ease and without splitting or fracture. At no time, during installation or when in service, can there be a failure at a weld, because there are no welds in J & L seamless boiler tubes.

3. The system of inspection followed in the J & L mills is so rigid and painstaking that only uniformly superior tubes reach the shipping platform.

All J & L boiler tubes are manufactured in accordance with the A.S.M.E. Boiler Code and comply with the A.S.T.M. specifications and the United States Bureau of Navigation and Steamboat Inspection General Rules and Regulations. They are in use in hundreds of boilers of both the fire tube and water tube type.

Specify J & L hot rolled seamless steel boiler tubes for *your* next job. A full range of sizes is available, from 1 inch O.D. to 6 inches O.D. inclusive.

J&L MANUFACTURES A COMPLETE LINE OF STEEL TUBULAR PRODUCTS, BOTH WELDED AND SEAMLESS.

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AMERICAN IRON AND STEEL WORKS
JONES & LAUGHLIN BUILDING, PITTSBURGH, PENNSYLVANIA

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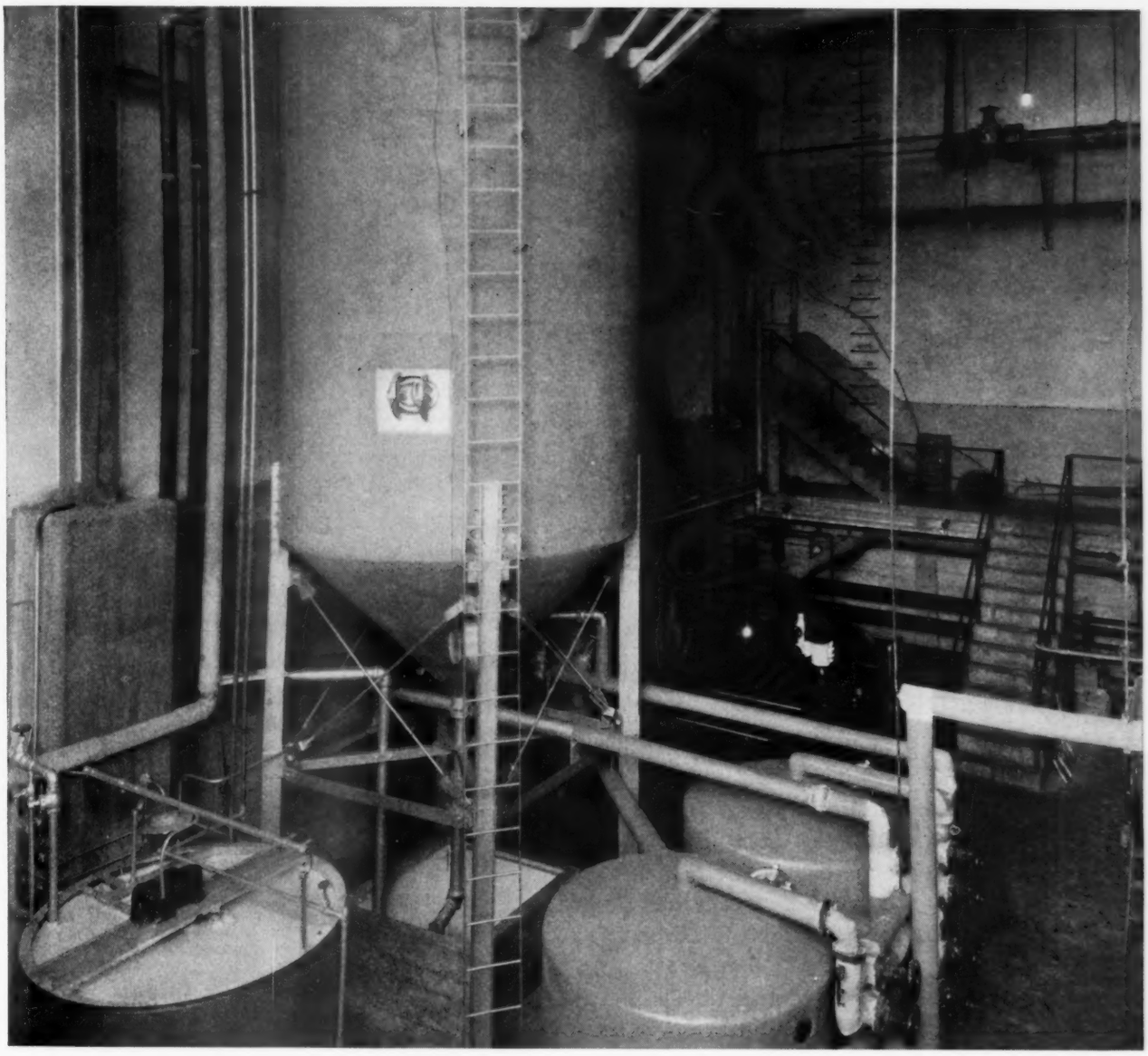
J&L STEEL



HOT LIME SODA water softening equipment

A large Iowa hospital softens all boiler feedwater with this up-to-the-minute money saver—the Permutit Hot Lime Soda Water Softener. Complete control of the softening formula is provided by Permutit's Electro-Chemical Feed which supplies soda-ash and hydrated lime in *exact* proportion to the volume of water being treated. When the composition of the water changes (as it often does) a simple finger-tip adjustment corrects the dosage to the proper amount instantly!

Permutit equipment may be purchased under the terms of the NHA. In most cases, installment payments are more than met by savings effected with Permutit.

Write for your free copy of our new 48-page book "Hot Lime Soda Water Softening." It is comprehensive, authoritative and up-to-the-minute. Write The Permutit Company, Dept. A5, 330 West 42nd Street, New York City.

Permutit

Water Conditioning Equipment

MODERN STEAM GENERATING UNITS

from 1000 to over 1,000,000 lb per hr

The accompanying drawings of units installed or on order show the extensive capacity range of CE steam generating units. Many more illustrations would be required to show combinations of all the different types of CE equipment—boilers, furnaces, stokers, pulverized fuel and heat recovery.

Leading companies in all fields of industry have selected CE units for requirements ranging from 1000 to over a million lb per hr, for pressures from those of small heating boilers up to 1800 lb—the highest pressure in commercial use in America—and for all types of fuel and load conditions. They have found in CE steam generating units the right answers to their individual problems because CE units are developed from the most complete line of equipment the market affords and from an experience correspondingly broad.

They have also found in the performance of their CE units the extra values that may be expected from equipment bearing the name of an organization that has made many of the most notable boiler plant installations of the present day.

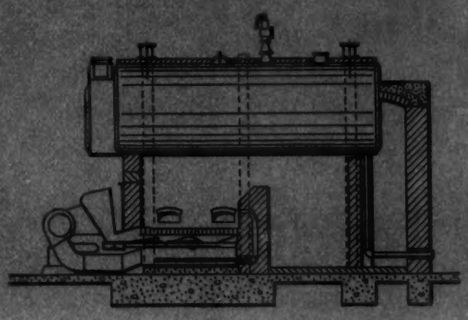
C·E

COMBUSTION ENGINEERING COMPANY, INC.

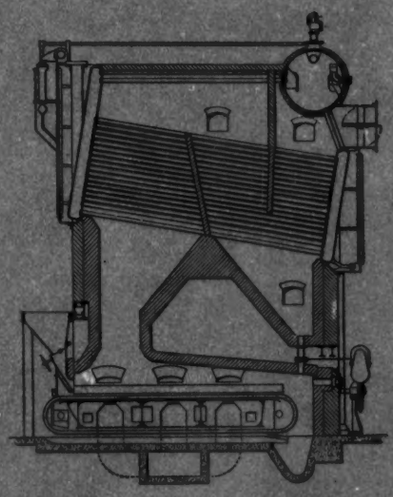
200 Madison Avenue **New York**

A-282

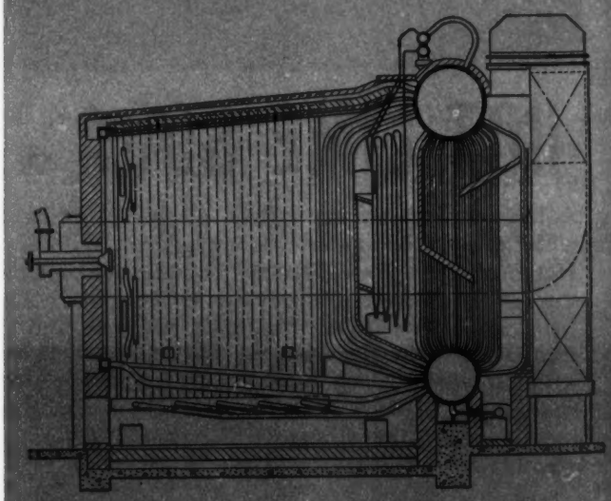
Canadian Associates: Combustion Engineering Corporation, Ltd., Montreal



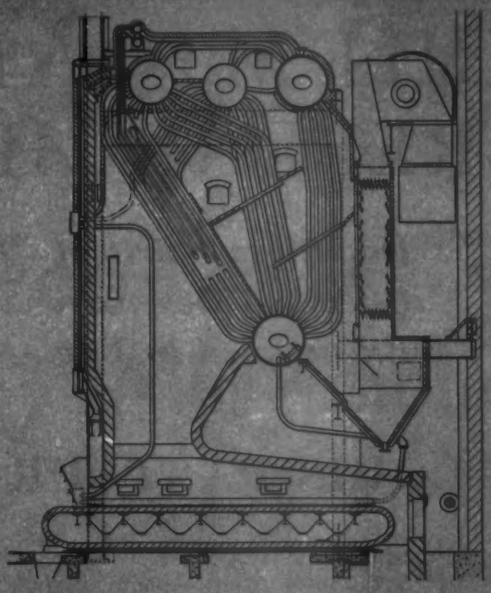
7000 LB—Unit comprised of CE Fire Tube Boiler and CE Underfeed Stoker (Type E), installed for the Reilly Tar & Chemical Corporation, Chicago, Ill. Similar units are available for capacities as low as 1000 lb per hr.



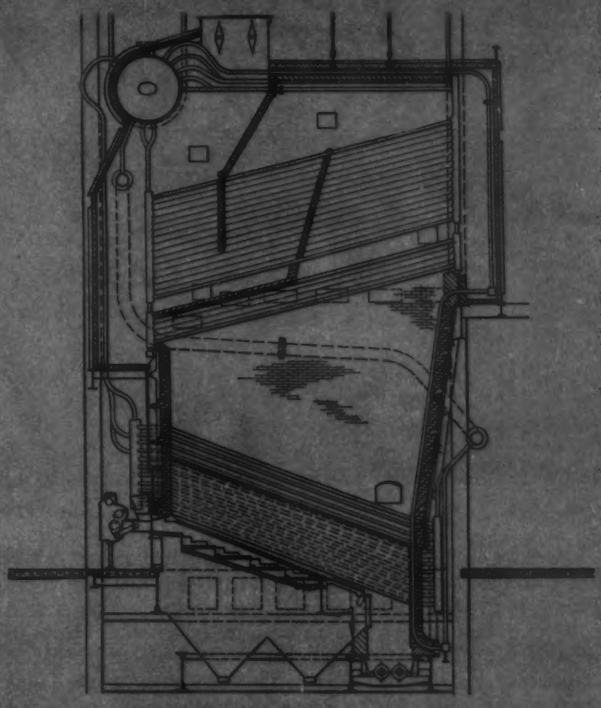
30,000 LB—Unit comprised of CE-Heine Cross Drum Boiler and CE-Coxe Traveling Grate Stoker, installed for Richards & Company, Inc., Stamford, Conn.



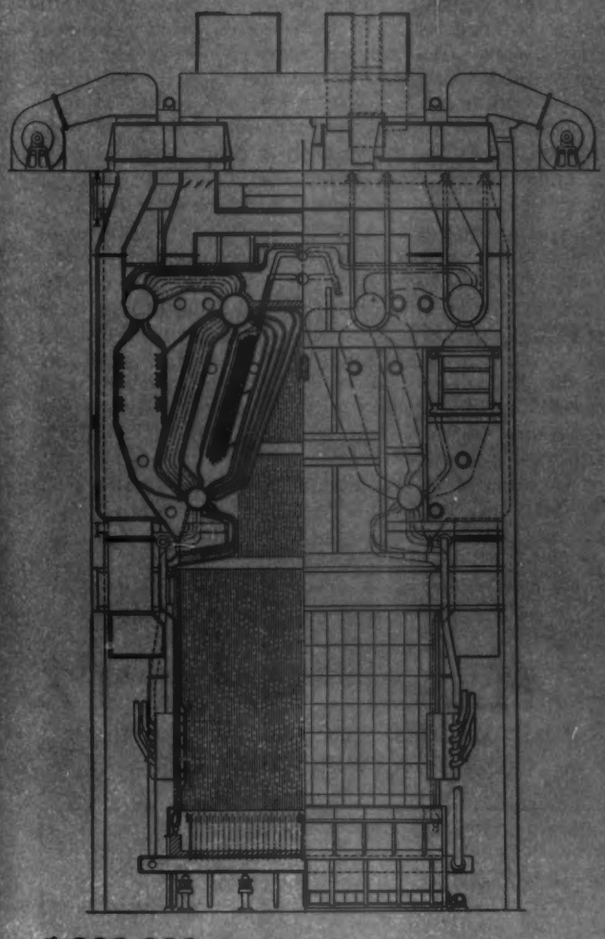
45,000 LB—CE Steam Generator (Type VU), recently purchased by the Fulton Bag & Cotton Mills, Inc., Atlanta, Ga. Units of this type are available in still smaller sizes and also in larger sizes providing capacities up to 200,000 lb or more.



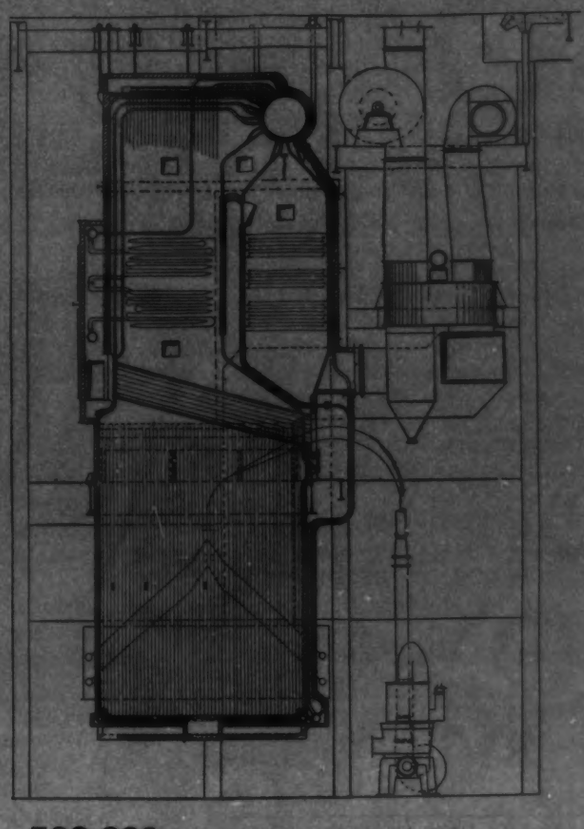
70,000 LB—Unit comprised of CE Bent Tube Boiler (Type VA) and CE-Coxe Traveling Grate Stoker, installed for Colgate-Palmolive-Peet Company, Jersey City, N. J.



200,000 LB—Unit comprised of CE Sectional Header Boiler and CE Multiple Retort Stoker, installed for U. S. Government Central Heating Plant, Washington, D. C.



1,000,000 LB—Unit comprised of CE equipment throughout, recently purchased for Logan, West Virginia, plant of Appalachian Electric Power Company. Pressure—1425; temperature—925 F; dry bottom furnace.



500,000 LB—Unit comprised of CE equipment throughout, recently purchased for Waterside Station, New York Edison Company. Pressure—1400 lb; temperature—900 F; slagging bottom furnace.

A Tribute To CHEMICAL RESEARCH

DR. H. L. KAHLER, RESEARCH DIRECTOR, BETZ LABORATORIES

Dauntless Spirit of Chemical Research Exemplified in Life of

LOUIS PASTEUR

The Life of Louis Pasteur, so beautifully portrayed and enacted by Paul Muni in the Warner Brothers picture, is typical of the quiet, unassuming, resolute and untiring personalities who contribute so much to human life and happiness through their unheralded research activities. Pasteur persisted in his research until he had attained his purpose, in spite of professional criticism and Royal displeasure. His contribution to the advancement of the medical profession is largely responsible for its present state of scientific perfection.

Other chemical research has contributed to the advancement of Industry and Commerce; specifically, in the field of Power Engineering, the plant efficiency and safety factors have been vastly improved through scientific methods of conditioning water. Not so many years ago, little was known concerning the Chemistry of Water Correction. To the research chemist, goes full credit for the present state of scientific perfection in maintaining the proper chemical balance of boiler water.

Several years ago, the Betz organization became interested in the adaptability of Colloidal Chemistry to water correction. The idea was new and there were no experience records to be used as a guide. Research chemists were employed to develop the idea, to supervise and study its application in the field, and to perfect the chemical reagents to be used. The continued efforts of the founders, their associates and other members of the technical staff of W. H. & L. D. Betz, have placed this organization in the enviable position of being a pioneer and authority on Colloidal Chemistry for water correction.

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EDITORIAL

Boiler Installation on the "Queen Mary"

In general, merchant marine practice in steam generation is charged with having advanced more slowly than land practice, notwithstanding certain recognized limitations imposed upon the power plant afloat. To what extent this has been due to precedent, to over-cautiousness or to a desire to follow long established arrangements of hull and machinery is debatable. There is ample precedent in land installations to warrant adopting certain practices, modified to suit marine conditions.

Outstanding examples are to be found in the boiler room of the "Queen Mary," which has twenty-four main water tube boilers of relatively small capacity and in that of the "Normandie," which has twenty-six. Compared with a lesser number of larger units, it will be apparent that the multiplicity of fittings, valves, piping and auxiliary equipment, in addition to the boilers themselves, must have greatly increased the initial cost, as well as necessitating more operating personnel. Greater economy in space and in operation would be expected from the larger units. Moreover, each of the "Queen Mary's" boilers has five forged drums, making one hundred twenty in all, and the space required by the numerous uptakes is approximately equivalent to that occupied by the boilers. While weight distribution is admittedly a factor in marine work, it would seem that structural design in a ship the size of the "Queen Mary" could easily cope with this factor.

Undoubtedly, many plausible reasons will be advanced in justification of a multiplicity of small boiler units but it is difficult for the engineer, accustomed to what has been accomplished in land practice, to accept them unreservedly, especially in a ship which in other respects embodies all that is latest.

Standardized Pressures and Temperatures

As noted elsewhere in this issue, there is a movement on foot in Germany to standardize steam pressures and temperatures. The values proposed appear adequate to meet any conditions that may be met in practice over a rather wide range and it is hoped through their adoption to lessen engineering calculations and simplify production in the manufacture of power plant equipment.

Standardization of design is not to be expected. Wherever it has been attempted it has been of short duration owing to the constant advance in practice, but a moderate degree in standardization of steam conditions, could neither retard progress nor appreciably affect applications. On the other hand, it would assist toward reducing both engineering and manufacturing costs. What the Germans are attempting might well receive serious consideration in this country.

The World Power Conference Program

Criticism of the plans for the forthcoming World Power Conference has lately appeared in the daily press with the assertion that the New Deal has run away with the Washington program by confining it to broad economic questions such as national and regional planning, conservation of power resources, regulation, social trends and organization of the fuel industries and public utilities.

Inasmuch as the whole setup of the American Committee has changed since the previous meetings at London in 1924 and Berlin in 1930, with the United States Government acting as host to the present Conference, it is not surprising, in view of the Administration's attitude on power matters, that the Washington program should be devoted to subjects of this nature. To what extent the Conference is to serve as an instrument for furthering the Government's power policies, as inferred by the press comments, remains to be seen.

It is the technical part of the program, however, that most concerns the engineers. In deference to the expressed wishes of foreign engineering groups technical phases of the Conference were added. While not a part of the Washington program, these will take the form of pre-conference and post-conference tours covering visits to outstanding power stations, hydro plants, research laboratories, refineries, coal- and oil-producing centers and railway shops and centers. Toward the end of each tour a round-table conference will be held to discuss technical matters arising out of what was seen on the tours, differences between American and foreign practice and problems incident to present trends in design and operating practice. One of these post-conference tours has been arranged to take in the Niagara Falls Regional Meeting of the American Society of Mechanical Engineers at which one day will be devoted to a symposium on present power plant practice. This will include very worthwhile papers by both American and foreign engineers. Other sessions will cover fuels, hydro and railway practice.

The arrangements for the technical program of the Conference are wholly in the hands of a committee made up of representatives of the major engineering societies and technical associations of the industries concerned. Washington's part in this phase of the program has been merely to co-ordinate the physical arrangements for the tours and to be assured that it fully measures up to the importance of the occasion.

While a large attendance is expected at the Washington meeting during the week of September seventh, it is likely that this part of the program will appeal most to the official delegates and Americans who may be interested in the economics of power supply. Others will attend who will want to observe the trend of the discussions and perhaps learn what is being done abroad. The engineers, it is anticipated, will find the meat of the Conference in the study tours and round-table discussions.

Radiography as Applied to Welded Boiler Drums

By E. C. CHAPMAN† and W. L. MARTIN††

The authors discuss the technique of X-raying welded boiler drums, the function of the Bucky grid in protecting the film from secondary rays, and the development of such equipment up to the 400,000-volt machine lately installed in the Chattanooga works for penetration up to 5 in. of boiler plate. Radiographs showing good and defective welds are reproduced.

THE application of the X-ray in industry for inspection of castings, welds, etc., is a comparatively recent development in consideration of its earlier use for medical diagnosis. It was first used in industry for examining castings for internal cavities such as blow holes and shrinkage cracks. The low voltage commercial equipment available for this work was capable of X-raying only light sections satisfactorily, and the market was not sufficient to warrant the expensive development work necessary to produce a satisfactory high-voltage tube for thick sections. Subsequent rapid development of fusion welding produced the necessary impetus for the development of high-voltage X-ray equipment, and the last five years has seen the voltage of industrial X-ray tubes increase from 200,000 to 400,000 volts.

Acceptance of fusion-welded pressure vessels by the A. S. M. E. Boiler Codes and insurance companies only came after the X-ray was demonstrated as a satisfactory method of non-destructive testing. The importance of such a method of testing ranks equally with that of being able to produce ductile weld metal of satisfactory physical properties.

Various other methods of non-destructive testing of welds have been used, such as the Sonic method by use of the stethoscope, and electrical resistance methods. These lack, however, the sensitivity of the X-ray by which flaws less than 1 per cent of the thickness are readily detected in steel plate 1 in. and under in thickness, and less than 2 per cent in plate up to 5 in. thick. The X-ray also provides a permanent record of the examination, which is an aid to inspection work. Until a better method of testing is developed, the X-ray is indispensable to the production of safe pressure vessels.

The Hedges-Walsh-Weidner Company was one of the first to install X-ray equipment for inspection of welded pressure vessels, the first welded boiler drum built under the A. S. M. E. Code Rules having been built and X-rayed in these shops. The highest powered commercial equipment available is in operation at this plant. This is a 400,000-volt unit capable of X-raying 5-in. steel plate satisfactorily. At present this company has two X-ray machines, the other being a 300,000-volt unit, purchased before the 400,000-volt unit was available. The Heine Boiler Company at St. Louis also has one machine of 250,000-volt maximum capacity.

What Are X-Rays?

X-rays belong to the electro-magnetic spectrum as do light rays and gamma rays, emitted by radium. All of these rays are of the same composition, differing only in wave length. They are a form of wave energy.

The power of such rays to penetrate matter is a function of their wave length. The ability of X-rays to penetrate steel and other materials opaque to light is due to their short length as compared to light waves.

Gamma rays have a much shorter wave length than X-rays, and therefore a much greater penetrating power. It is possible by this means to examine vessels in service and parts which are inaccessible to the X-ray equipment.

Source of X-Rays

Fig. 1 is a diagram of an X-ray tube. The tube is a highly evacuated glass bulb containing a wire filament *A* and a tungsten target *B*.

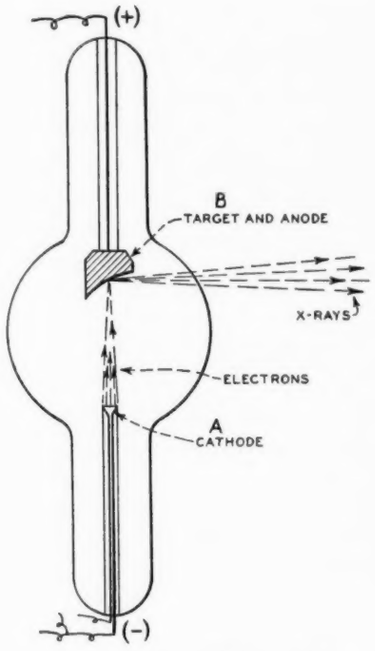


Fig. 1—Diagram of X-ray tube

† Research Engineer and †† X-ray Technician, The Hedges-Walsh-Weidner Company (Subsidiary of Combustion Engineering Company, Inc.), Chattanooga, Tenn.

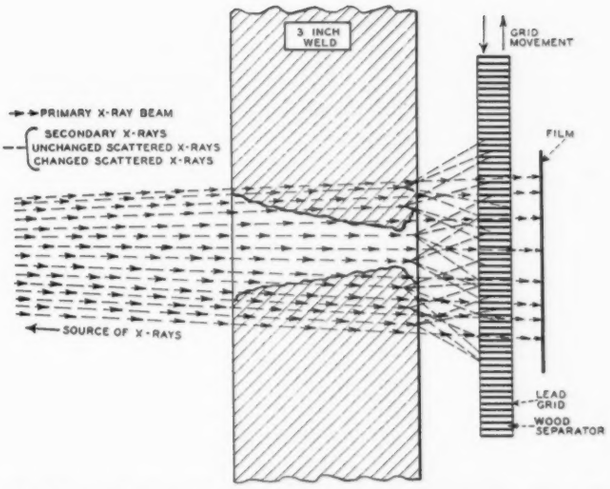


Fig. 2—End view of grid illustrating its function in radiography

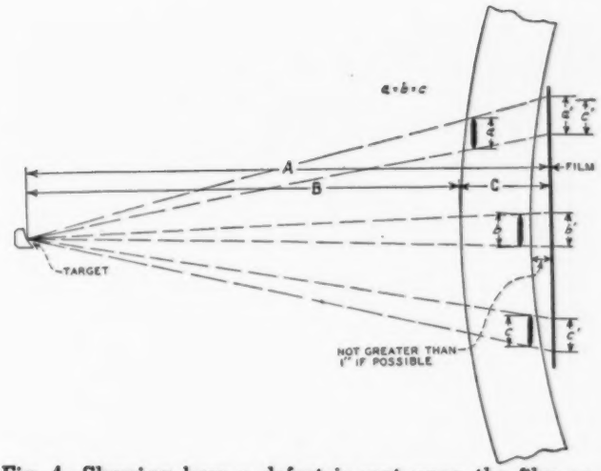


Fig. 4—Showing how a defect is cast upon the film as a shadow

Code requirements for limitation of distortation and magnification of defects are $\frac{B}{C}$ = minimum of 7; or when Bucky Screen Grid is used $\frac{B}{C}$ = minimum of 5

The transfer of electrical energy into X-ray energy is briefly as follows: The source of power is a 220-volt ac line, the voltage being stepped up by means of transformers and changed from alternating to a uni-directional current by means of rectifiers. This secondary voltage (60,000 volts and up) is then impressed upon the X-ray tube.

When the wire filament becomes heated, electrons are put in motion, breaking away from the filament surface. The high voltage hurls the electrons violently against the tungsten target and X-rays result from the impact.

The development of tubes that will stand up under continuous operation at such high voltages has been the biggest problem and limiting factor in the X-raying of heavy plate.

X-Rays and Matter

The resistance of matter to X-rays, or the ability to absorb them, is a function of the atomic weight of the material. It is easier to penetrate 5 in. of steel than $^1/_8$ in. of lead.

Only a small portion of the rays entering steel pass through without alteration. Some rays strike atoms, resulting in secondary rays of longer wave lengths. Other rays are deflected and have their wave lengths changed in so doing. After alteration, many of these rays are absorbed by the steel. The number of primary, unabsorbed and unchanged rays that emerge, depends on the thickness of the material, the wave length (determined by tube voltage) and the time of exposure.

The images of discontinuities, such as slag pockets, porosity, cracks, etc., are obtained upon a photographic film, in the form of a shadow picture of the defect.

Most engineering and industrial materials can be explored for internal defects by means of the X-ray. Nickel, stainless and other alloy steels, copper, brass, aluminum and many non-metallic materials, are readily examined. Alloy and stainless steels require practically no change in exposure time from that required for carbon steel.

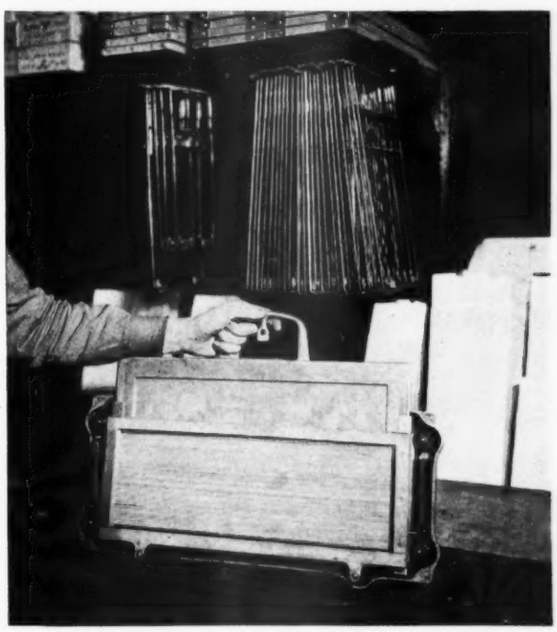


Fig. 3—Bucky diaphragm with front removed, showing grid and film in place. The holder is lead lined on back and sides to protect the film from secondary rays

Bucky Diaphragm

After considerable experimentation, the General Electric X-Ray Corporation has been successful in designing a Bucky grid adaptable to industrial radiography, although such grids have been used for years in medical radiography. Its function is to eliminate secondary and scattered radiation, allowing only those rays to strike the film which travel in a radial direction from the focal spot of the X-ray tube. Clean-cut images of defects are thus obtained—images not marred and blurred by indiscriminate scattered radiation. Two years' experience with the Bucky in radiographing weld seams at the previously mentioned plant has proved conclusively that its use should be mandatory in connection with heavy plates. Employment of the Bucky is desirable with all plate thicknesses above $2^1/_2$ in., and necessary with all thicknesses above 3 in. Frequently, serious defects in welds of such thicknesses cannot be diagnosed from radiographs made without the aid of a grid.

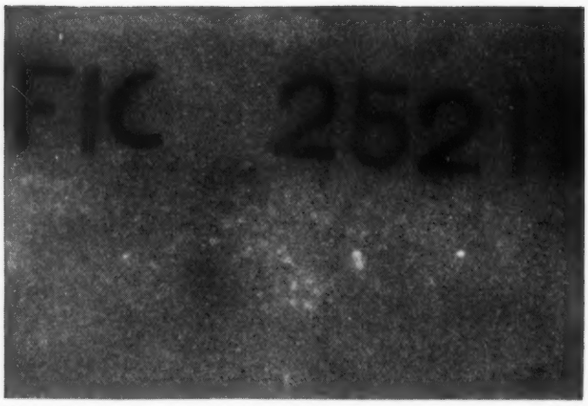


Fig. 5—Showing very bad porosity, and unacceptable

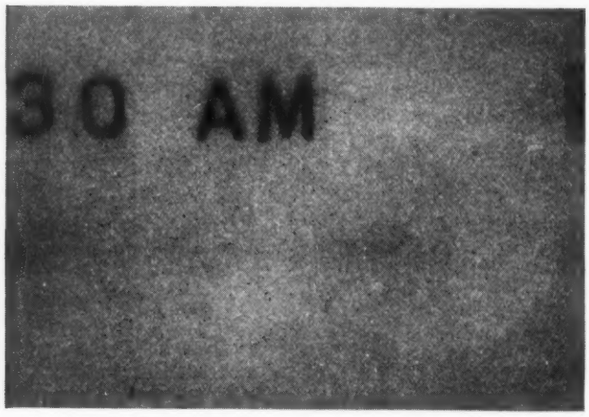


Fig. 6—Radiograph of good weld with little porosity

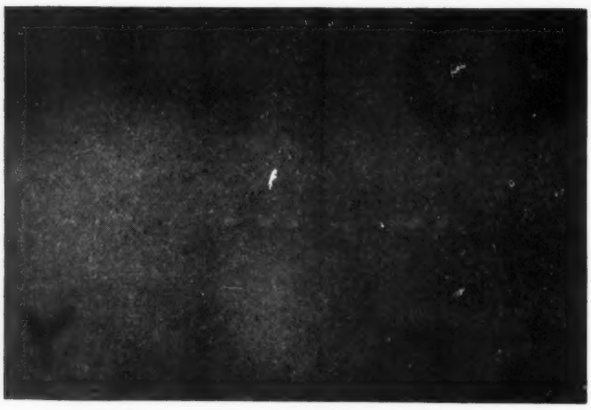


Fig. 7—Weld containing unacceptable slag inclusions

Fig. 8—Radiograph showing cross crack in plate (made without Bucky grid)

Such a grid is composed of alternate thin layers of wood and lead about $^3/_8$ in. to $^1/_2$ in. in depth. It is oscillated between the work being X-rayed and the film during the time of exposure. This oscillation prevents objectionable images of the lead vanes on the film. The diagram, Fig. 2, shows an end view of such a grid and illustrates how it is used in radiographing a weld seam. A study of this diagram will disclose how the Bucky effectually functions in the absorption of adverse rays emanating from the back of the plate being X-rayed. All such rays are absorbed by the lead vanes except those which are substantially parallel with the primary rays. Fig. 3 is a photograph of a Bucky diaphragm with front removed showing the grid and film in place. The holder containing the cassette is lead lined on the back and sides to protect the film from secondary rays.

In radiographing plate thicknesses up to $1^3/_4$ in. there is very little difference between films taken with the Bucky and those taken without it. The probable explanation of this is that in thin-plate radiography the percentage of secondary and scattered radiation is small compared with the unabsorbed primary radiation. As plate thickness increases, this ratio increases. Comparative radiographs of 4 in. thick welds (that is, with and without the Bucky) have shown that in "non-Bucky" films about 80 per cent of the built-up density is due to secondary and scattered radiation. Aside from being useless, the effect of such radiations cuts down both definition and contrast, making difficult the detection of defects. Such radiography of 4 in. thick welds is not sufficiently sensitive as to disclose certain types of defects as much as $^1/_2$ in. in depth.

We have the first grid that was developed for experimental use, and also the later model developed by several years of experimental work by the General Electric X-Ray Corporation.

Radiographs and Defects

X-ray film is almost identical with photographic film and the photographic effect of X-rays is similar to that of light rays. The images of defects are recorded upon the film as a result of the greater intensity of the incident radiation in their projection. Fig. 4 shows diagrammatically how a defect is cast upon the film in the form of a shadow. Such defects will be magnified to various degrees, depending upon their location with respect to the films and the source of radiation.

A defect such as *a* (Fig. 4) will be magnified more than defect *c*, and both will be somewhat distorted due to their angular projection. Defect *b* is in the optimum location for obtaining the truest image on the film.

In order to reduce magnification and distortion, the Codes specify a minimum ratio of the distance $\frac{B}{C} = 7$ without the Bucky grid, and 5 when the grid is used. The maximum length of film used is 17 in. Curvature of the shell in X-raying girth seams adversely affects distortion. Films used on girth seams are shorter for small diameter drums in order to maintain the above ratio with a reasonable focal distance. A 10 in. length film is normally used for girth seam pictures.

The intensity of radiation of an X-ray beam varies inversely as the square of the distance from the source of radiation. Since the intensity of radiation determines

the time of exposure for a given voltage or wave length, the focal distance must be maintained at a minimum for X-raying heavy plate.

The types of defects encountered in welding fall into three main groups: (1) Porosity or gas inclusions; (2) Slag and lack of fusion; (3) Cracks.

Fig. 5 is a radiograph showing very bad porosity. that is definitely unacceptable. The A. S. M. E. Boiler Code has attempted to set up standards of acceptable porosity for all thicknesses of plates but such standards have not as yet been fully accepted. Fig. 6 is a radiograph showing a good weld with very little porosity. Slag inclusions and lack of fusion are the result of poor work on the part of the welder. Such defects are definitely limited in length and number by the Codes. Fig. 7 is a radiograph of a weld containing unacceptable slag inclusions.

Cracks of any description must be repaired for acceptance. Fig. 8 shows a weld cross crack in $3^1/_2$-in. plate. This radiograph was made without using the Bucky grid. The grid was used in taking Fig. 9, a radiograph of the same defect, and shows the crack more clearly defined.

If a defect is of such a character that it must be removed, it is advantageous if its location with respect to the inside or outside of the weld is known. Considerable saving is made in the cost of chipping and welding if this can be determined. Experience has shown that most porosity occurs near the surface, or near the top of the "U" groove. Slag inclusions and lack of fusion are more commonly located in the bottom of the "U" groove.

The size and location in the weld of a defect can be visualized by making stereoscopic radiographs. We have a special "stereoscope" illuminator for such investigation. Stereoscopic radiographs are made by taking two angular exposures of the same defect. This is expensive and is only used on special work. Some judgment as to the depth of a defect can be used from knowledge of the width of the weld groove at various depths. Defects in the side wall near the surface will appear at a greater distance from the centerline of the weld than those in the side wall near the bottom of the weld. Often the location of a defect cannot be determined by simple interpretation and a "guess" must be made in deciding which side of the weld to chip.

Production X-Raying

PROCEDURE

Usually the longitudinal seams of a vessel are X-rayed before the heads are welded on. This is done only for convenience. Many vessels are completely welded before being X-rayed, depending on whether or not a machine is idle.

Equal spaces are marked off on the seams and numbered consecutively. The numbers are stamped on the drum for a permanent record. Each film bears two consecutive numbers, one at each end. Each picture taken overlaps the preceding and following ones by from 2 to 3 in., and each number thus appears on two films. This procedure insures that every inch of the weld is fully X-rayed and examined. Also, each film bears the job number and the drum number. The numbers on the films are the result of placing lead numbers on the outside of the shell opposite the film during exposure.

Fig. 9—Same crack as in Fig. 8 but made with Bucky grid

Other marks appearing on the film are thickness gages or penetrameters. The A. S. M. E. Boiler Code requires that the X-ray technique be such as to determine quantitatively the size of defects with thickness equal to and greater than two per cent of the thickness of base metal. Fig. 10 shows the types of gages used when the reinforcement is retained and when it is removed. It is required that the gages be placed near the end of the exposed portion of the weld with the thin edge of the gage toward the end.

We recommend and practice the removal of the weld re-inforcement, both inside and outside, before X-raying. Welds are chipped and ground flush with the plate. Therefore, type "A" penetrameter is used almost exclusively in this shop. The penetrameter is made of steel, built up as shown in steps, so that the same gage may be used for any thickness plate within the range it covers. Each step of the gage is drilled with a hole as shown. It is required that the X-ray technique be such that the step representing 2 per cent of the plate thickness, be distinguished without question on the radiograph.

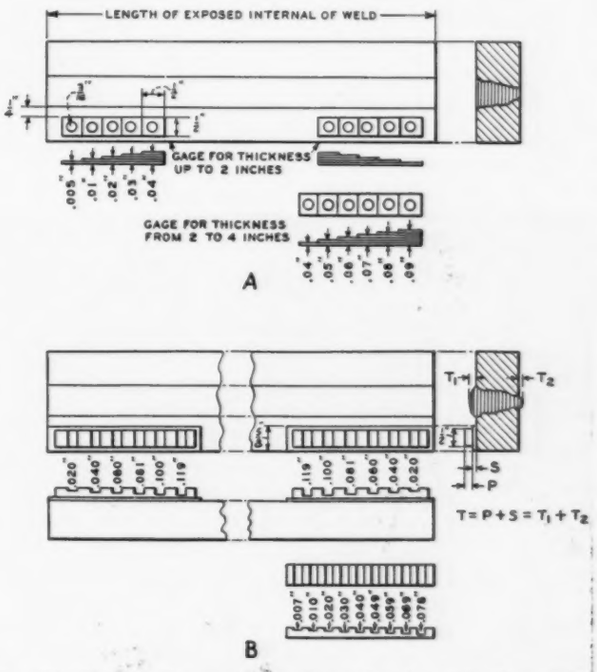


Fig. 10—Types of gages (penetrameters) used when reinforcement is retained and when it is removed

Fig. 11—Making an exposure with Bucky in place. It is important that the Bucky be placed normal to the primary X-ray beams in order that the primary rays may pass straight through the gaps between the lead strips, while the secondary rays are cut off

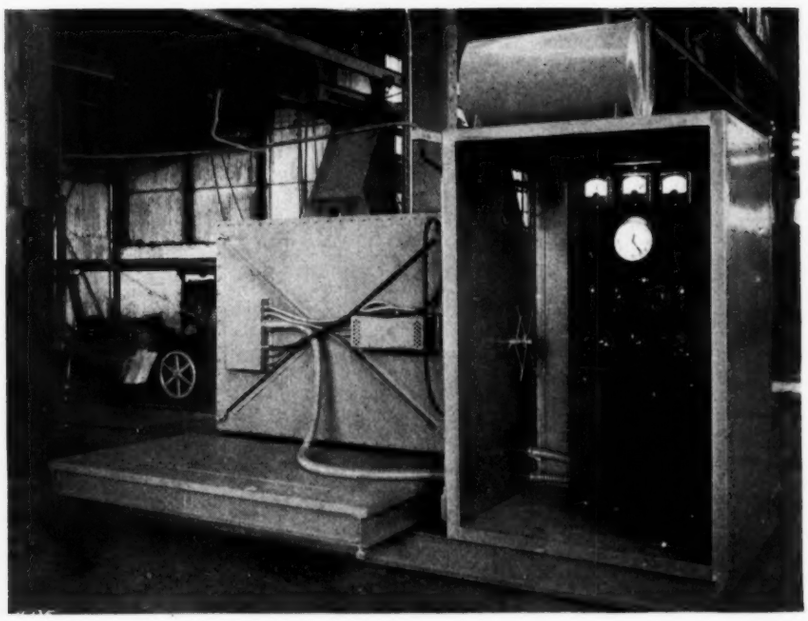


Fig. 12—Control panel for X-ray machine with housing

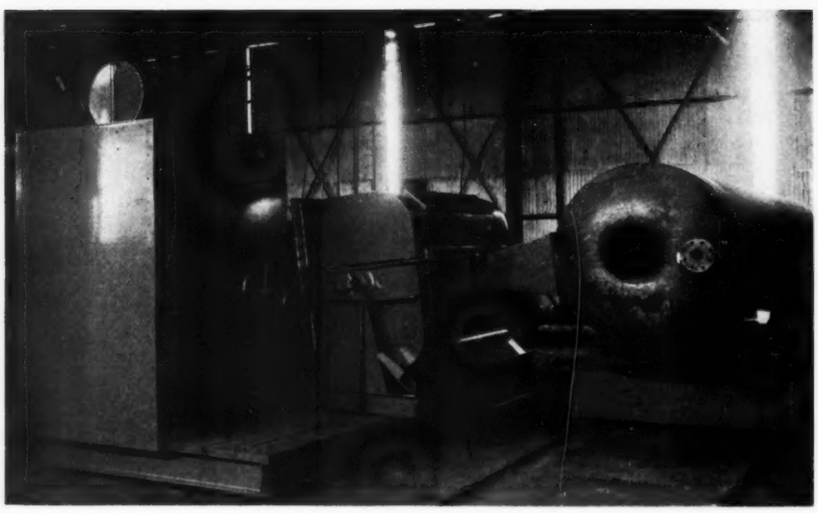


Fig. 13—Welded drum in place for X-raying weld that attaches the head to the shell

It is not always possible to accurately judge the depth of a defect by density contrast. The irregularity of some defects, such as slag inclusions, limits the accuracy of such determination to practical estimates. The depth of slag inclusions is usually not more than the depth of one bead of weld metal and generally less.

A true density comparison of the image of a crack with that of a penetrameter gage requires that the plane of the crack be normal to the surface of the plate throughout its depth and that its width be constant. Cracks are the result of the very high contraction stresses set up in a seam during the process of welding. These stresses are of such a magnitude as to cause a crack to gap open when it occurs and their direction causes the crack to form in a plane normal to the plate surface. This is advantageous for detection by means of the X-ray.

The purpose of the penetrameter gage is primarily for a check on the X-ray technique.

Such a gage, however, does enable a visual comparison of densities. At present, great reliance must be placed on experience in making such comparisons. It is exceedingly doubtful that any method of gaging the depths of defects by a comparison of densities of images will ever be developed which will reduce to any extent the importance of experience in interpretation.

There is no question that side wall lack of fusion or cracks may be partially obscured by X-raying with the reinforcement retained. The A. S. M. E. Boiler Code X-ray Sub-Committee is now recommending that the practice of removing the reinforcement be made mandatory for X-rayed vessels.

Repairs

Repairs due to slag inclusions and local porosity are part of the normal routine in any shop that subjects its vessels to X-ray examination and follows the Code requirements for the removal of such defects. The defects are removed with a chipping hammer and tool, re-welded and re-X-rayed.

Making repairs in welded seams involves no difficulties. An interesting and most advantageous feature of welded work is that a seam properly repaired and X-rayed is 100 per cent equivalent to one perfectly welded on the first trial. Repair work, however, is costly and time consuming. Welding methods have improved in the last several years to such an extent that the human element presents the greatest obstacle to the complete elimination of "chipping" due to objectionable inclusions.

The percentage of defective welds is usually very small and many vessels are completely welded with no repairs subsequently required.

Code requirements for weld quality, as revealed by the X-ray, are, of course, based on the final complete radiographs and are not concerned with repair work done prior to final examinations. Physical fatigue of the welder from hours of continuous welding, sometimes in cramped positions, accounts for a good percentage of slag inclusion encountered. It is not always possible for a welder to assume a comfortable position in welding.

The sensitivity of the X-ray is attested by visual inspection of inclusions as they are removed by the chipper. Many such defects are completely included in one thin chip and are never located by the chipper. The result is that he often will chip completely through a seam in order to make certain the inclusion has been removed.

Length of Films—Time of Exposure

The films used on longitudinal seams are 17 in. long by $3^1/_2$ in. or $4^1/_2$ in. wide. Those for girth seams are 10 in. long and $3^1/_2$ in. wide. Allowing for overlapping of the films, the net length of exposed weld is, for plate under $2^1/_2$ in., 15 in. for the longitudinal seams and 8 in. for the girth seams. For plate above $2^1/_2$ in. thickness, this is reduced to 12 in. for the longitudinal seams and 6 in. for the girth seams.

The time for each exposure increases rapidly with the thickness of plate. Using the same technique with respect to tube voltage and amperage and the same focal distance, the time required for a single exposure on $2^3/_4$-in. plate is approximately 45 sec, $4^1/_2$-in. plate one hour and 5-in. plate $3^1/_4$ hr. These exposure times are based on using the Bucky grid. Above 5 in., a fraction of an inch additional thickness increases the exposure time to such an extent as to make this thickness a practical limit with the 400,000-volt X-ray tube. For any plate up to $2^1/_2$ in., the difference in time is only a matter of seconds, which is small in comparison to the preparation time required in setting up the casette.

A typical vessel, 42 in. o. d. by 20 ft long in the longitudinal seam, would require twenty longitudinal exposures and twenty-two exposures for each girth seam. Assuming two girth seams, the total time of exposure for a vessel $2^3/_4$ in. thick would be 64 × 45 sec plus 2 min × 64 (allowance between exposures for setting up the film) = 2 hr, 56 min.

For a vessel 5 in. thick, the time required would be 210 hr. In X-raying heavy boiler drums, considerable X-raying time is saved when the girth seams are reduced in thickness.

The expense involved in X-raying will, of course, increase rapidly with the exposure time. Although the film cost is practically constant for any thickness, labor, overhead and depreciation of equipment are almost in direct proportion to time.

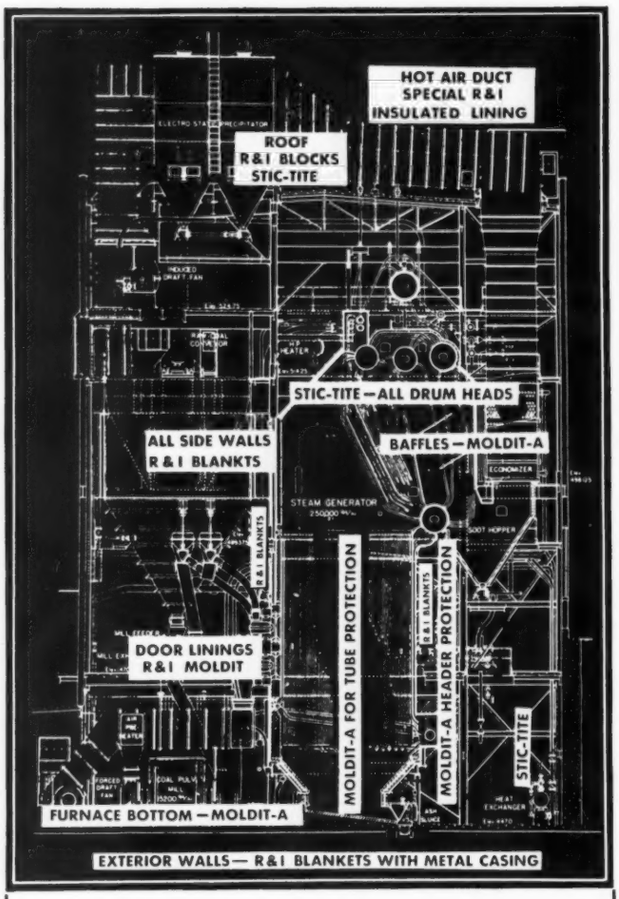
After the vessel is shipped, all films are placed on file for future reference should any question be brought up concerning the quality of the welds.

The present Codes require that only seam welds be X-rayed. Typical nozzle construction involving fillet welding cannot be X-rayed with satisfactory results. Nozzles can be X-rayed if an inserted construction is used, in which the only welding involved is a butt weld between the inserted nozzle flange and the shell plate. Double-welded butt joints, of uniform section, offer the best subjects for X-ray examination.

Stress-Relieving

Unless otherwise specified, all X-raying is done before the vessel is stress-relieved. This avoids more than one stress-relieving treatment, which would be necessary on vessels requiring repairs. Many vessels have been X-rayed both before and after stress-relieving. Advocates of this practice fear the development of cracks as a result of the heat treatment operation. Results at our shop have failed to substantiate this theory.

The A. S. M. E. Code requires that all vessels welded according to the Boiler Code or U-68 of the Unfired Pressure Vessel Code, be stress-relieved. Non-stress-relieved vessels are allowed by the Unfired Pressure Vessel Code with limitations placed on thickness, operating pressure and operating temperature.



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Coordination of BOILER AUXILIARIES*

By A. F. SPITZGLASS
and G. K. O'CONNOR
Republic Flow Meters Company

The most difficult problem in the application of combustion control to boilers is the proper coordination of the fuel-burning auxiliaries, to obtain accurate and efficient control of steam pressure, combustion and furnace draft. The authors discuss this with reference to boilers fired by stokers, pulverized coal, gas and oil.

THE two most important characteristics of boiler auxiliaries in regard to their effect on the control situation are range and flexibility, for they must have sufficient range to cover the entire requirements of boiler ratings. Questions of range and flexibility are more frequently encountered in industrial boiler plants than in central stations because of the character of the load and the small number of boilers in operation.

Boilers in base-load stations are often considered as base-load boilers. From the control standpoint, however, there is a difference between boilers operated at base load and those operated in a base-load plant. In base-load plants the steam pressure must be controlled to take care of minor load changes and variations in heat input caused by variations in fuel and air supply.

Controlled Variables

A combustion control system regulates three variables, steam pressure, combustion and furnace draft. Steam pressure is controlled by changing the heat input to the boiler to balance the steam demand. In gas, oil and pulverized coal-fired boilers, where fuel is burned in suspension heat input responds to the rate of fuel supply to the furnace. In these boilers steam pressure is controlled by changing the fuel supply. In stoker-fired boilers the immediate heat input responds to the air flow through the fuel bed. Here steam pressure is controlled by changing the air flow.

Combustion is controlled by changing either the fuel or air to maintain the desired fuel-air ratio. In gas-, oil- and pulverized coal-fired boilers, since the steam pressure is controlled by changing the fuel supply, the fuel-air ratio must be controlled by changing the air flow. The fuel-air ratio of these boilers can be accurately controlled only if the range and flexibility of the draft equipment match the range and flexibility of the fuel supply. In stoker-fired boilers, since the steam pressure is controlled by changing the air flow, the fuel-air ratio must be controlled by changing the stoker speed.

Furnace draft is controlled by maintaining a balance between the forced and the induced draft. If, for example, the air flow through a boiler is changed by means of a change in induced draft, the forced draft must be instantly changed a corresponding amount to maintain the furnace draft.

Pulverized Coal-Fired Boilers

With pulverized coal-fired boilers heat input is controlled by changing the fuel supply to the burners. Hence, any lack of range or flexibility impairs the regulation of steam pressure. With the storage or bin system there is seldom any problem of flexibility, since fuel supply responds immediately to change in feeder speed. However, to cover the range of boiler ratings, manual operation of burners is sometimes necessary.

With the direct-firing system control of fuel input is more difficult. Because of the storage lag of the pulverizer the change in fuel input to the furnace does not rapidly respond to change in raw coal feed to the mill. The effects of pulverizer lag may be overcome by primary air control, by mill-speed control or by overfeeding on load pickup and underfeeding on load drop. One method of primary air control which has given excellent results in a number of installations is shown in Fig. 1. With this method the measured quantities of primary air and fuel feed are controlled with separate master-controlled regulators.

In addition to permitting accurate control of steam pressure and combustion this method also has the advantage of improving ignition at low boiler ratings by increasing the fuel fineness and reducing burner velocities. Measured control of primary air prevents mill plugging since an increase in coal storage in the mill produces an increased air velocity within it. This increased velocity causes an increase in the rate of coal removal from the mill and thus limits the coal storage.

One requirement of primary air control is that the primary air blower furnish sufficient pressure not only to overcome resistance of the pulverizer, burner and piping but also to provide an extra margin for control.

Stoker-Fired Boilers

As a rule, few problems are encountered in controlling fuel input to stoker-fired boilers. The fuel input is controlled by changing the stoker speed. The speed range of the drive and the gear ratio between the drive and the stoker should be able to satisfy the range of boiler ratings without resort to manual gear change. Underfeed stokers require an extra margin of speed range to take care of varying feeding characteristics of the fuel.

* From a paper at the Midwest Power Conference, Chicago, April 20 to 23, 1936.

Speed control is usually satisfactory if the stoker is driven by an engine turbine or constant-speed motor with variable-speed transmission. Field-controlled dc motors should have a sufficient number of rheostat points to provide incremental speed steps. With three- and four-speed motor drives the proper fuel bed thickness may be obtained by means of "totalized" regulation. However, when this type of drive is used the proper change in fuel bed agitation with small load changes is not obtained.

Fig. 2 shows diagrammatically the method of controlling the speed of a pole-changing stoker motor by means of "totalized" regulation. One shaft of the "totalizer" is driven by the stoker motor while the other is driven by a variable-speed pilot motor. The stoker-speed regulator controls the speed of the pilot motor and together with the master controller and air-flow regulator maintains the speed of the pilot motor in proportion with the boiler air flow. The "totalizer" compares the totalized revolutions of the stoker motor with that of the pilot motor and intermittently changes the speed of the stoker motor to equate these values. In this manner average stoker speed is held proportional to the boiler air flow.

Oil- and Gas-Fired Boilers

There is seldom any question of flexibility in oil- or gas-fired boilers. Heat input responds immediately to movement of the fuel valve and steam pressure control is comparatively simple. The range of many oil and gas burners is limited, since reducing fuel and air supply to the burner reduces the burner velocities and impairs the mixing of fuel and air. Because of the limited burner range the functioning of the combustion control system depends on proper manual changing of burners and burner tips to maintain the control equipment within the operating range of the burners.

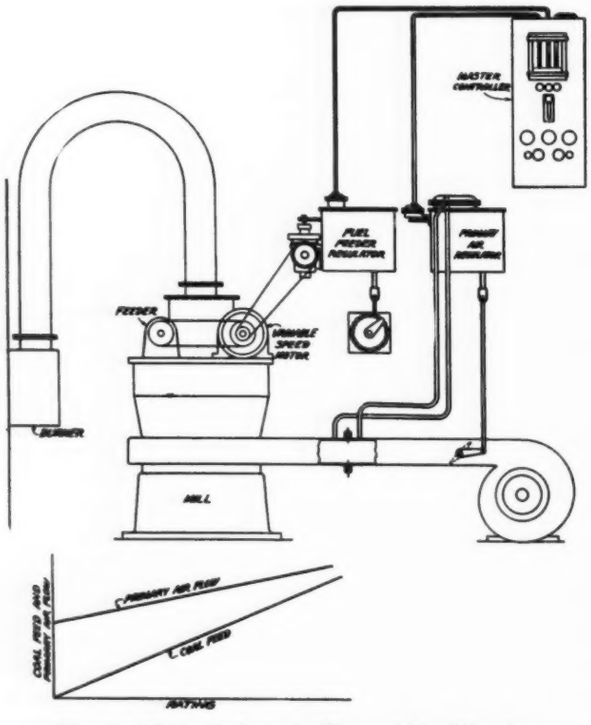


Fig. 1—Method of controlling unit mill using primary air control

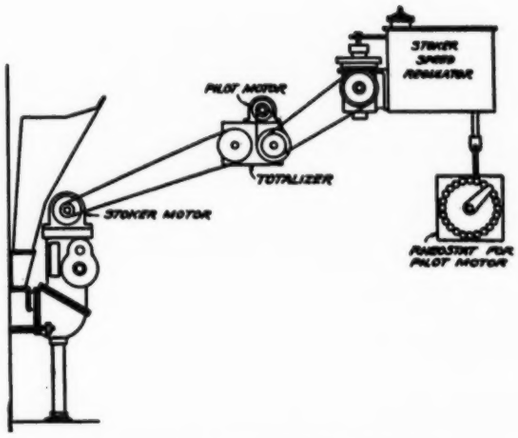


Fig. 2—Control of four-speed stoker motor

Air Flow and Furnace Draft

In any boiler control the air flow may be controlled by changing the induced draft, and the furnace draft by changing the forced draft, or the air flow may be controlled by changing the forced draft, and the furnace draft by changing the induced draft. Although there is difference of opinion as to which method is superior, both are used successfully.

Either the forced or the induced draft may be changed by damper control, fan-speed control or by controlling both damper and fan speed. With turbine drive or hydraulic-coupling drive, fan-speed control alone may be used for the forced draft over the entire range and for the induced draft from maximum down to the natural draft. For boiler ratings less than those which can be accommodated by natural draft, damper control must be used in addition to fan-speed control. Maximum economy of fan power with the latter method is obtained by operating the damper and fan-speed changing device in sequence so that the damper is wide open whenever the fan speed is above the idling value.

The hydraulic coupling provides a means of obtaining variable fan speeds with constant-speed fan motors. The change in fan speed is accomplished by changing the quantity of oil in the coupling and is a function of control valve movement multiplied by time. Control of fans driven through hydraulic couplings therefore differs from that of turbine- or motor-driven fans where the fan speed is a function of throttle valve or controller position only. For this reason regulators of conventional design which are intended for turbine- and motor-speed control and for damper control will not provide satisfactory control of hydraulic coupling-driven fans.

Slip-ring and pole-changing motor-driven fans require damper or vane control as well as fan-speed control to provide small changes in draft. Minimum expenditure in fan power requires that the control equipment be adjusted to increase the fan speed only when the damper is in a wide open position and to decrease it before the damper has throttled to any great extent. Combined damper and fan-speed control is more successful with slip-ring motors than with pole-changing motors since the greater number of speed steps provides less draft disturbance during speed changes.

Modernizing the Conners Creek Power Plant—VIII

Models and Test Performance

By SABIN CROCKER

Engineer, The Detroit Edison Company

The present article concludes the series which has related in detail the engineering problems involved in the rebuilding of the Conners Creek Power Plant to provide practically double the capacity in the same space at higher steam pressure and temperature and to improve greatly the station heat rate through the installation of large modern steam generating and turbine units, improved firing equipment and replacement of the Rankine cycle by the regenerative cycle of feedwater heating. Test performance is compared with that specified in the designs.

Models Aid Design and Layout

SCALE models have been used extensively by the Company's engineers for many years as an aid in designing power and central-heating plants. The rebuilding of Conners Creek justified the use of models equally as much as the building of a completely new plant such as Delray Power House No. 3.[1] Since all the models are made to scale, they serve to display in three dimensions the true interrelation of equipment and piping, which portrayal is especially valuable to designing engineers in the preliminary stages of architectural and equipment-layout studies, and to the management in authorizing the finally approved design.

After preliminary studies of a project are discussed in conference by engineers of departments contributing to the design, a model of the proposed layout is built to scale out of wood, wax and copper wire. Each model is inspected by those concerned in plant design with a view to: (1) eliminating interference between building steel and piping or equipment; (2) providing sufficient head room and dismantling space; and (3) obtaining good appearance and operating convenience. Models are progressively revised as the design advances and before working plans of the various drafting divisions are approved, until a generally satisfactory layout is assured. In this way the responsible engineers can obtain a better perspective of the job than would otherwise be possible, at least without spending an excessive amount of time in examining the many detailed drawings prepared by various drafting divisions. That some ten-years' experience with models has thoroughly justified their use is attested by the improved quality of plant layouts and the fewer number of field changes required after erection. In fact, the successful replacing of the old Conners Creek units with bigger and more elaborate equipment can be attributed in a large measure to painstaking model studies.

The model of the plant above ground level, Fig. 70, shows Nos. 8 and 9 rebuilt turbine-generators and new No. 1 high-pressure boiler. The feedwater heaters of Unit 8 can be seen in the photograph. This model was particularly useful in determining how these heaters could be best arranged in the very limited space available. Fig. 71 shows the disassembled model with the boiler and part of the feedwater system removed to display the systematic layout of piping. Building steel does not appear in this view as it was attached to one of the disassembled sections of the model. An example of rebuilding around essential existing equipment in the old plant can be seen in this figure where the new piping is arranged to avoid the hollow vertical rectangular boxes representing the casings of two existing coal conveyors. This is a typical example of how coordination of design, preventing as it does all but very occasional minor interferences, fully justifies the comparatively small expense entailed in the building and use of models.

[1] See "Models Make for Accessibility in Delray Piping," by Frank Thorp and R. M. Van Duzer, Jr., *Power*, Vol. 70, p. 956, December 17, 1929.

Latest Performance Figures

At the end of January 1936, following the completion and running in of the third 30,000-kw unit, the old low-pressure plant was retired from normal every-day operation and kept in readiness for emergency service only. During the months following placing the old plant in reserve, it was possible to obtain a better indication of the probable annual plant efficiency than could be done during mixed operation. While these monthly data are not looked upon by the Company as bearing the same weight as annual averages, they do indicate that an overall plant performance considerably better than that of 1935 (see February installment) can be expected. Performance tests of boilers and turbines have been run in recent months and a synopsis of the data from these tests is given here in Tables XVIII and XIX.

Since the design of the coal-handling equipment does not provide means of weighing coal to individual boilers without a temporary re-arrangement of coal spreaders and the installation of special coal-weighing equipment, the Company has adopted the heat-balance (or heat-loss-measurement) method of boiler testing, feeling that it supplies sufficiently accurate comparisons between the

TABLE XVIII

COMPARISON OF BOILER HEAT-BALANCE TEST RESULTS WITH DESIGN DATA NEW BOILER NO. 4

	Nominal Excess Air 15 Per Cent									
	Design	Test	Design	Test	Design	Test	Design	Test	Design	Test
Coal burning rate, lb per hr	11,800		16,900		22,800		30,600		39,300	
Steam generated in boiler and water walls, lb per hr	130,000	131,000	176,000	187,000	237,000	250,000	313,000	326,000	395,000	415,000
Steam temperature in superheater-outlet header,[1] F	840	817	850	837	850	839	850	841	850	835
CO_2 at boiler outlet,[2] per cent	15.3	14.9	15.4	15.0	15.6	14.9	15.7	15.2	15.7	15.3
CO at boiler outlet, per cent	0.02	0.0	0.02	0.0	0.03	0.2	0.11	0.2	0.3	0.3
Gas temperature: boiler outlet, F	556	562	598	598	657	640	737	734	833	738
economizer outlet, F	420	459	449	491	486	523	535	605	591	610
air heater outlet, F	272	274	280	289	297	313	323	365	351	359
Temperature of air supplied stoker, F	340	354	344	365	359	373	384	414	416	408
Combustible in ashpit refuse, per cent	6.7	5.5	6.3	6.1	8.6	7.0	11.4	8.5	14.5	10.3
Proximate coal analysis; per cent: moisture	4.0	4.7	4.0	4.9	4.0	6.1	4.0	6.9	4.0	7.1
volatile matter	34.4	31.5	34.4	31.7	34.4	30.9	34.4	30.1	34.4	30.1
fixed carbon	53.9	56.2	53.9	56.0	53.9	56.2	53.9	56.4	53.9	55.9
ash	7.7	7.6	7.7	7.3	7.7	6.8	7.7	6.6	7.7	6.9
Ash softening temperature, F	2,500	2,700	2,500	2,700	2,500	2,700	2,500	2,700	2,500	2,700
Heating value of coal as fired, Btu per lb	13,200	13,290	13,200	13,290	13,200	13,200	13,200	13,120	13,200	13,020
Total boiler-unit auxiliary power,[3] kwhr/hr		43		88		141		323		622
Apparent boiler-unit efficiency by difference,[4] per cent	89.6	90.5	89.7	90.4	89.0	89.6	87.9	87.4	86.4	87.3

[1] Superheater-outlet steam temperature controlled to obtain desired steam temperature at turbine throttle.

[2] Heat-balance test disclosed appreciably in leakage of air through fly-ash hopper below last gas pass in boiler, which condition is being remedied.

[3] Includes power for fans, stokers, clinker-grinders, combustion air control and other miscellaneous boiler-unit equipment.

[4] All items normally found in a heat balance were determined in this boiler test by the heat-balance method. Since the apparent efficiency had to be found by difference, because the coal was not weighed, it includes the expected small errors in obtaining and computing heat-loss quantities, usually referred to as unaccounted-for losses. Due to the care with which this test was conducted, these errors are estimated at less than ±0.5 per cent. The heat equivalent of the auxiliary power is not included in the heat balance.

various boilers in the plant and, in fact, approaches for most practical purposes the accuracy of the weighed-coal, weighed-water method. As explained in the notes to Table XVIII the heat balance employed in these tests includes all items that would normally appear in a complete boiler test with additional items such as radiation and convection loss measured with accurate instruments operated by the Company's research engineers, and loss by combustible in fly ash in the flue gas. The ratio of the metered boiler output to the output plus measured losses is only an apparent efficiency, although it is believed to approach the true efficiency, within a possible tolerance of plus or minus one-half of one per cent.

Up to March 1, 1936, the four boilers installed have operated an average of approximately 70 per cent of the elapsed time since each was placed in service, with an additional 16 per cent "in reserve" due to the excess of boiler capacity over turbine capacity. The steaming hours of the boilers will increase when more turbine capacity is installed, as well as with passing of the recognized experimental-development stage.

Table XIX shows a comparison of test results with design data for 30,000-kw turbine-generator No. 9. Unit performance appears satisfactory. Minor operating difficulties have been met and overcome. While the amount of air withdrawn from the condenser is not considered as excessive for the initial operation of a new unit, close attention is, nevertheless, being given to reducing air inleakage to the unit which, it is expected, will eventually be brought down to one cubic foot per minute (referred to 70 F, 30 in. hg, and dry), as is obtained with the 50,000-kw Delray units. The turbines up to March 1, 1936, have operated an average of 84 per cent of the elapsed time since they were placed in commission, plus an 8 per cent "in reserve" period due to load conditions. With the high area loads experienced in the winter of 1936, all three 30's ran at full load for an appreciable part of the time.

Conclusion

Comparison of the rebuilt plant reviewed in this series of articles with the 1915 Conners Creek plant, as described by Dr. C. F. Hirshfeld in an A.S.M.E. paper of that year, emphasizes the marked advance in power-plant design which has taken place during the past two decades. In the new Conners Creek a comparatively complicated heat balance is replaced by a simpler one of higher efficiency. Steam at high pressure and uniformly maintained high temperature is generated in the modern boilers, supplemented by air heaters and economizers which were not previously used. Combustion air control is witness of a marked development in the fuel-burning field. Many economies of operation are introduced to supply electric power at reduced cost. With the progressive replacement of old units and the installation of new turbine-generators and boilers, the plant heat rate approaches a gratifyingly low figure.

The work of rebuilding the plant has been successfully carried out with a minimum of interference in operation of existing equipment, and with the plant at all times carrying its proper share of the system load. The interchange of both ac and dc power between the old plant and the new plant for the operation of auxiliaries was effected without involved cross-connections between

TABLE XIX

UNOFFICIAL COMPARISON* OF TEST PERFORMANCE WITH DESIGN DATA NO. 9 TURBINE-GENERATOR, CONNERS CREEK POWER HOUSE

	Design	Test	Design	Test	Design	Test	Design	Test
*Turbine-generator***								
Load on generator terminals, gross kw	14,530		19,930		24,570		29,940	
Throttle steam-flow rate, lb of steam per gross kwhr generator output	9.36	9.19	9.15	9.15	9.09	9.09	9.20	9.27
Heat rate, Btu per gross kwhr generator output	10,490	10,300	10,060	10,060	9,830	9,830	9,760	9,830
Feedwater Heaters								
Temperature leaving 4th stage heater, F	331	327	352	348	369	363	388	388
Temperature leaving 8th stage heater, F	276	279	294	294	308	307	323	326
Temperature leaving 11th stage heater, F	220	227	236	240	247	252	259	265
Temperature leaving 14th stage heater, F	153	145	165	159	174	166	182	180
Condenser and Auxiliaries								
Air withdrawn from condenser in cu ft per min***							1.0	5–7
Power for turbine and condenser auxiliaries, ac and dc together, in per cent of main generator load		2.2		1.9		1.8		1.6

* These design data were computed by Detroit Edison engineers from performance curves furnished by the manufacturer. Both design and test figures reflect the performance of the extraction heaters as well as that of the turbine. The tests were made by the Detroit Edison Co., and inasmuch as the manufacturer did not assist in conducting them and was not represented at the time, the results are unofficial.

** Turbine-generator test performance corrected to 600-lb gage, 825 F, 1 in. hg back pressure, and design temperature of feedwater leaving 4th stage heater, evaporator not operating.

*** Referred to 70 F, 30 in. hg, and dry.

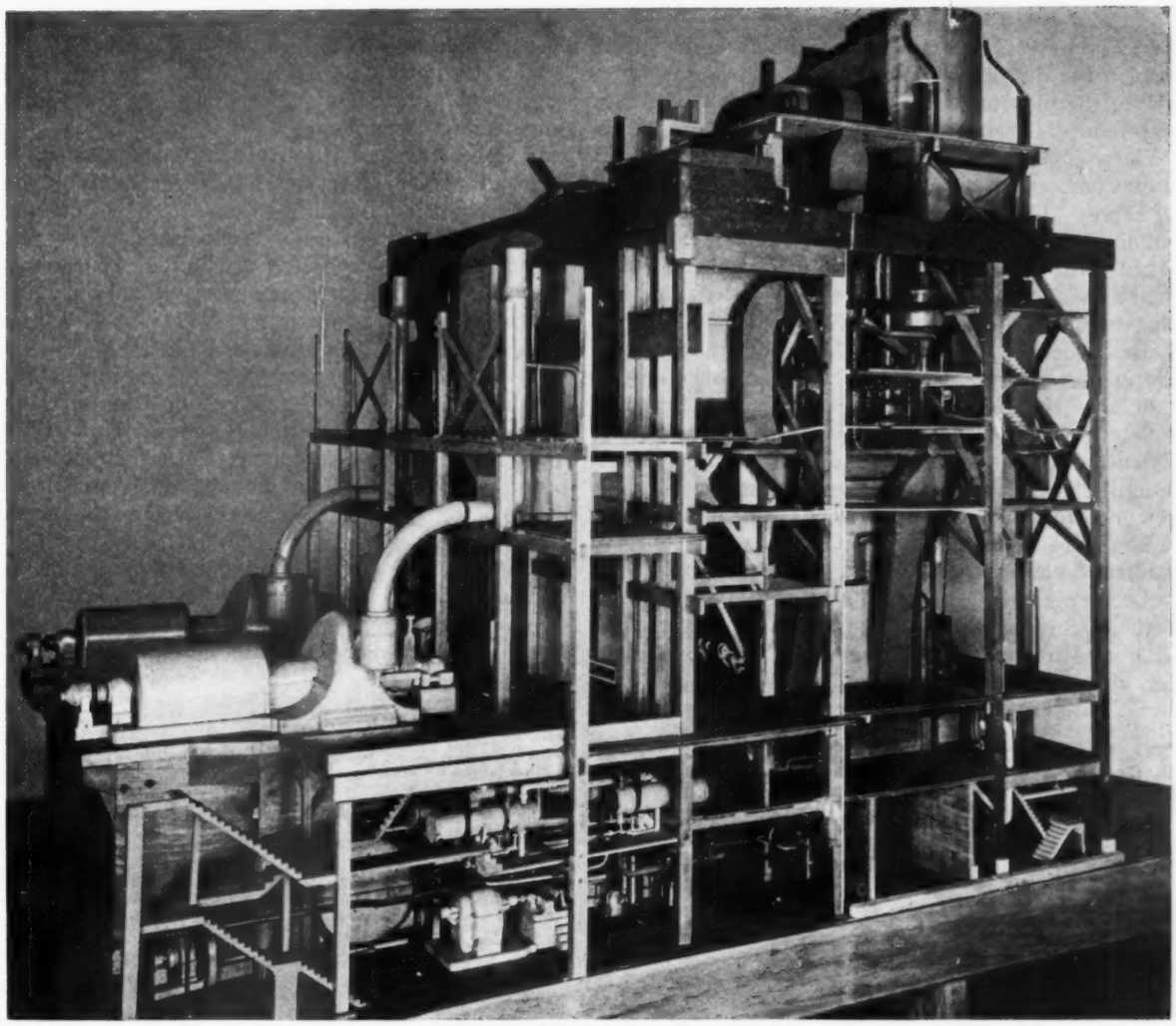
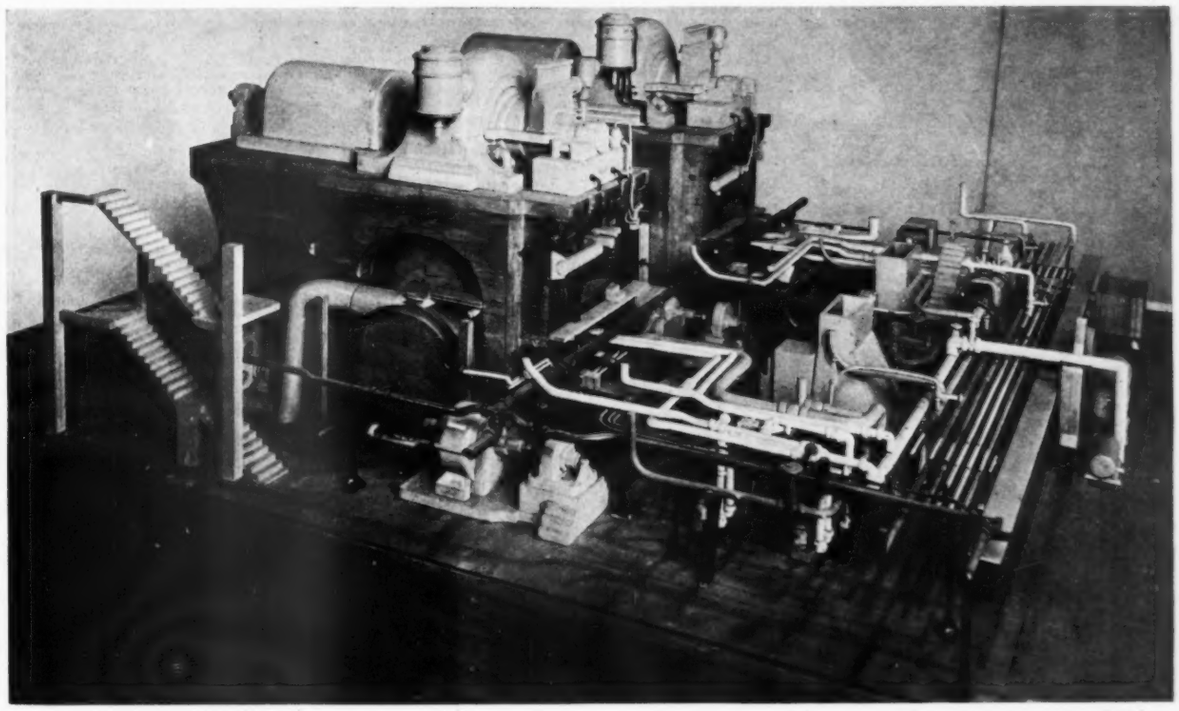


Fig. 70 (above)—Model of new turbine-generators Nos. 8 and 9 and new boiler No. 1
Fig. 71 (below)—Model shown in Fig. 70 partially disassembled to show piping and concealed equipment



electrical circuits. Complications which might have arisen in the division of condensate and makeup water between the old and the new equipment were foreseen and provided for without difficult operating procedure.

A large measure of responsibility for The Detroit Edison Company's plant design is placed on the operating staff heads. The organization of a project such as the rebuilding of Conners Creek is so devised that the men charged with the operation and maintenance of the Company's existing plants, and who will have similar authority over the new plant when put into service, exercise a coordinating and directive control over the entire project from its inception to determination of the last detail. It is largely because of this fact that the completed plants closely reflect the day-to-day operating experience of the men who have to make the equipment function, which incidentally insures prompt acceptance of new construction by the plant force taking it in charge.

It is also of interest that the Company has its own drafting and construction force of experienced men who have been engaged for years on successive projects and are thoroughly versed in Detroit Edison practice. Work by the drafting and construction bureaus is carried on for, and under the direction of, the various operating departments as though they were owners who had engaged an outside contracting firm to execute both design and construction. There is no separately organized engineering department responsible as such for planning and approving new work, although the Company does have a central engineering division which advises various departments in a consulting capacity.

The rebuilding program is fully justified, the management believes, as peculiarly fitting the circumstances at Conners Creek, being from every point of view the logical procedure there after twenty years of useful power-plant life. The modernized new equipment now installed will be able to supply the rapidly increasing power demand of the highly industrialized Conners Creek area up to about double the firm capacity of the old plant. Most opportunely, the rebuilding has also been an effective means of providing employment for the drafting and construction force during the economic depression.

Continuation of the program, now well under way, will permit a well ordered and, if necessary, a rapid development of one of the major power sources in the Detroit area in a manner calculated to keep step with the city's rather vigorous industrial growth.

Tabulation of Principal Equipment, Conners Creek Power Plant of The Detroit Edison Company

TURBINE ROOM

Main Turbines

**30,000 kw, 600-lb gage, 850 F, 1800 rpm; 1 two-row Curtis and 17 single-row stages, bled at 4th, 8th, 11th and 14th stages.

60,000 kw, 600-lb gage, 850 F, 1800 rpm; 1 two-row Curtis and 13 single-row stages, bled at 4th, 8th and 11th stages.

General Electric Company.

Main Generators

*No. 8—37,500 kva at 0.8 power factor, 12,200 volts, direct-connected exciter, 140 kw, 250 volts.

*No. 9—33,000 kva at 0.9 power factor, 12,200 volts, direct-connected exciter, 140 kw, 250 volts.

No. 10—40,000 kva at 0.75 power factor, 12,200 volts, direct-connected exciter, 170 kw, 250 volts.

Nos. 11 to 14—80,000 kva at 0.75 power factor, 14,400 volts, direct-connected exciter, 180 kw, 250 volts.

General Electric Company.

Main Condensers

*30,000-kw Units 8, 9 and 10, 27,000 sq ft, two pass, 5744 tubes, 18 ft 3¼ in. long, 1 in. OD, No. 18 gage.

*60,000-kw Units 11 and 12, approx. 40,000 sq ft, single-pass, about 6500 tubes, 24 ft 0 1/16 in. long, 1 in. OD, No. 18 gage.

*60,000-kw Units 13 and 14, 35,200 sq ft, two pass, 7476 tubes, 18 ft 3¼ in. long, 1 in. OD, No. 18 gage, with external air cooler, 2100 sq ft fin tube surface.

Worthington Pump and Machinery Corp.

Main Circulators

*30,000-kw Units—one per condenser, 42-in. horizontal double-suction volute pump, 36,000 gpm, 16-ft head, 360 rpm; *General Electric* dc motor, 200–250 hp, 235 volts, 280–375 rpm.

*60,000-kw Units—two per condenser, one 36-in. horizontal double-suction volute pump, 30,000 gpm 23 ft head; *General Electric* dc motor, 300 hp, 235 volts, 350–450 rpm: one 48-in. horizontal double-suction volute pump, 60,000 gpm; *General Electric* dc motor, 225–450 hp, 235 volts, 150-300 rpm.

Worthington Pump and Machinery Corp.

Main-Unit Dry Vacuum Pumps

*30,000-kw Units—one per unit, *Laidlaw-Dunn-Gordon* two-stage single-acting type, 25 cfm; *General Electric* dc motor, 30–100 rpm, 12–40 hp.

*60,000-kw Units 11, 12 and 13, one per unit, *Laidlaw-Dunn-Gordon* two-stage single-acting type, 30 cfm; *General Electric* dc motor, 50–100 rpm, 25–50 hp.

60,000-kw Unit 14; triple-element three-stage steam air ejector with three-stage condenser, steam consumption, 285 lb per hr for each element.

Worthington Pump and *Machinery Corp.*

Oil Coolers

*Duplicate vertical type—*Schutte & Koerting Co.*

Oil Filtration

*Portable *De Laval* separator.

Batch Filter

**SB Bowser Co.*

* Denotes old equipment re-used with or without alteration.

** New main turbine includes exhaust casting, pedestal bearings, oil base, parts of governor and atmospheric relief valve from old 20,000-kw unit.

Generator-Air Coolers

Nos. 8*, 9* and 10; 60,000-70,000 cfm, 13,940 sq ft air cooling surface. Nos. 11, 12, 13 and 14, 110,000 cfm, 15,520 sq ft air cooling surface.

General Electric Company.

Auxiliary Turbines

No. 1 dc unit 2150-kw cross-compound; other dc units, 3144-kw cross-compound; for both sizes, hp turbine, 4996 rpm, 600 lb per sq in. g, 825 F, 10 lb per sq in. g back pressure; lp turbine, 3622 rpm, 1-in. hg back pressure.

General Electric Company.

Water Walls

Effective tube and fin surface; boilers 1 & 2, 2050 sq ft, boilers 3, 4, 13 and 14 2200 sq ft: integral-block surface; boilers 1 & 2, 270 sq ft, boilers 3, 4, 13 and 14, 280 sq ft: furnace volume 11,000 cu ft, heat release 50,400 Btu per hr per cu ft at maximum load.

Combustion Engineering Co., Inc.

Superheaters

Elesco temperature-compensating type, 1420 sq ft radiant surface on radiant-superheater side, 1890 sq ft radiant surface and 6120 sq ft convection surface on radiant-convection-superheater side; steam temperature 850 F throughout the operating range.

The Superheater Company.

Auxiliary Generators

No. 1 dc unit, 2000-kw dc generator, 240 volts, 450 rpm; other dc units,* two tandem-connected 1440-kw dc generators per turbine, 240 volts, 450 rpm.—*General Electric Company.*

Auxiliary Condensers

No. 1 dc unit, 2220 sq ft; other dc units, 3470 sq ft; all two passes, welded cylindrical shells.—*Worthington Pump* and *Machinery Corp.*

Auxiliary Circulators

No. 1 dc unit, 12-in. horizontal volute pump, 21 ft head, 2700 gpm; *Westinghouse* dc motor, 15–25 hp, 450–900 rpm: other dc units, 16-in. horizontal volute pump, 33 ft head, 4280 gpm; *Westinghouse* dc motor, 20–50 hp, 230 volts, 430–695 rpm.—*Worthington Pump* and *Machinery Corp.*

Auxiliary Dry Vacuum Pumps

Twin-element two-stage steam air ejectors with inter- and after-condenser, steam consumption No. 1 dc unit, 150 lb per hr, other dc units 240 lb per hr.

Worthington Pump and Machinery Corp.

BOILER ROOM

Boilers

Special double-ended bent-water-tube 6-drum "VV" type, 710-lb gage, 330,000 lb per hr nominal full load, 420,000 lb per hr maximum load, 26,790 sq ft saturated surface.

Combustion Engineering Co., Inc.

Economizers

Two per boiler, horizontal single-pass counter-flow return-bend fin-tube type; total surface, boilers 1 and 2, 8620 sq ft, boilers 3, 4, 13 and 14, 8490 sq ft.

Combustion Engineering Co., Inc.
The Superheater Co.

Air Heaters

Two per boiler, counter-cross-flow plate-type, total surface 28,980 sq ft. air temperature 390 F.—*Combustion Engineering Co., Inc.*

Stokers

Taylor double-ended underfeed type, 12 retorts, 41 thin (29 standard) tuyères, projected grate area 557 sq ft, coal capacity 42,000 lb per hr at maximum load; Jones 2-speed silent reduction gear; *Westinghouse* dc motor, 2½-15 hp, 250–2000 rpm, 115–230 volts; clinker grinders, two rolls, 20-in. diam., ⅜ to 9 rph, two *General Electric* dc motors, 250–2000 rpm, 5 hp, 230 volts.
American Engineering Co.

Combustion Air Control

Air-flow regulators, 72 per boiler.—*A. W. Cash Co.*
Uniform-scale 6-point air-flow gage.—*The Hay Corp.*
Venturi nozzles and damper-position indicators.—*The Detroit Edison Co.*

Forced-draft Fans

One per boiler, double-inlet Sirocco, capacity 101,000 cfm at 68 F, 15.78 in. water static pressure; *Westinghouse* dc motor, 230 volts, 50–400 hp, 370–740 rpm.—*American Blower Corp.*

Induced-draft Fans

One per boiler, double-inlet two-thirds double-width Sirocco, capacity 181,000 cfm at 346 F, 15.00 in. water static pressure; *Westinghouse* dc motor, 230 volts, 88–700 hp, 365–730 rpm.—*American Blower Corp.*

Soot Blowers

Welded integral-type, special deslagging nozzles. All piping within boiler setting.—*The Detroit Edison Co.*

Water Columns

Four per boiler.—*Diamond Power Specialty Corp.*

PIPING AND VALVES

Pipe and Pipe Fabrication

National Tube Co.
Pittsburgh Piping & Equipment Co.
Murray W. Sales Co.
The Detroit Edison Co.

High-Pressure Superheated Steam
Parallel-Slide Valves
Lunkenheimer Co.
Valve Motor Operators
Culler-Hammer Co.
Stop-and-Check Valves
Schulte & Koerting Co.

High-Pressure Boiler-feed and Saturated Steam Wedge-Gate Valves

Lunkenheimer Co.
Crane Company.

Feedwater Regulators

Two per boiler, *Copes* valves with tension-type thermostat, automatic constant-pressure-drop regulation, capacity (1) 255,000 and (2) 180,000 lb per hr.—*Northern Equipment Co.*

Safety Valves

Two 4-in. high-lift pop safety valves per boiler, capacity 238,000 lb per hr each of saturated steam. One 3-in. per superheater, 78,000 lb per hr of steam. Two 1½-in. per economizer 182,000 lb per hr of water
Crosby Steam Gage and Valve Co.

Blow-off Valves

Four per boiler.—*J. Hopkinson and Co., Ltd.*

Miscellaneous Small High-Pressure Valves for drains, by-passes, instruments and so on.
Globe Valves

Consolidated Ashcroft Hancock Company, Inc.
Lunkenheimer Co.

Miscellaneous Low-Pressure Valves and Regulators

Atwood and Morrill Company.
Chapman Valve Mfg. Co.
Consolidated Ashcroft Hancock Co., Inc.
Crane Company.
Fisher Governor Co.
Lunkenheimer Co.
Ruggles-Klingemann Mfg. Co.

FEEDWATER SYSTEM

Stage Heaters

High-pressure four-pass condenser-type heaters with desuperheating zone, welded-steel-plate construction, tongue-and-groove lock head, water pressure 1000 lb per sq in.
Low-pressure four-pass condenser-type heaters, welded-steel-plate construction, bolted head, water pressure 200 lb per sq in.
30,000-kw units, surface, 4th and 8th 1340 sq ft, 11th 1363 sq ft, 14th 1025 sq ft.
60,000-kw units, surface 4th 2690 sq ft, 8th 2630 sq ft, evaporator-condenser 1655 sq ft, 11th 2100 sq ft.—*Foster Wheeler Corp.*

Evaporators

*Units 9 and 10, No. 40 horizontal steel shell, effective heating surface 133 sq ft, single-effect. 60,000-kw units, Horizontal welded-shell submerged-type. self-scaling single-effect bent-tube; heating surface, 194 sq ft; disengaging surfact 45.9 sq ft.—*The Griscom-Russell Company.*

Storage Tanks

Welded-steel construction, 40,000 gallons.

Combination Pumps

Boiler feed and hotwell, two per main unit:
30,000-kw units—BFP, 647 gpm, 1920-ft head; HWP, 608 gpm, 284-ft head; motor-driven unit, *Westinghouse* 4800-volt 3-phase ac slip-ring motor, 101–505 hp, 1412–1780 rpm; turbine-driven unit, 550 hp 1780 rpm.
60,000-kw units—BFP, 1320 gpm, 1938-ft head; HWP, 1232 gpm, 376-ft head; motor-driven unit, *Westinghouse* 4800-volt 3-phase ac slip-ring motor, 350-1100 hp, 1320-1785 rpm; turbine-driven unit, 994 hp, 1770 rpm.
De Laval Steam Turbine Co.

Lift Pumps

*Two per main unit: 30,000-kw units, 660 gpm, 140-ft head; *General Electric* dc motor, 35 hp, 1200 rpm: 60,000-kw units, 1000 gpm, 130-ft head, *Westinghouse* dc motor, 50 hp, 1200 rpm.
Worthington Pump and Machinery Corp.

Heater-drain Pumps

One per main unit: 30,000-kw units, 203 gpm, 440 ft head; *Westinghouse* dc motor, 22–50 hp, 1620–1830 rpm; 60,000-kw units, 376 gpm, 447 ft head; *Westinghouse* dc motor, 16–75 hp, 1300–1770 rpm.
De Laval Steam Turbine Co.

Hot-Drip Pump

250 gpm, 100-ft head; *Westinghouse* dc motor, 900–1800 rpm, 5–10 hp.
Pennsylvania Pump & Compressor Co.

Auxiliary-Unit Hotwell Pump

One per unit; 65 gpm, 135 ft head; *Westinghouse* dc motor, 7½ hp, 1750 rpm.—*Worthington Pump and Machinery Corp.*

Heating-Returns

*Three automatic *Jennings* vacuum heating pumps, 22 gpm, 15-lb head; ac motor, 1½ hp, 1800 rpm.—*The Nash Engineering Corp.*
*Cadillac condensation meter, 12,000 lb per hr.—*Central Station Steam Co.*
*Two 4/3 centrifugal condensate pumps, 300 gpm, 40-ft head; dc motor, 7½ hp, 1150 rpm.—*Union Steam Pump Co.*

INSTRUMENTS

Indicating and Recording Pressure Instruments

Consolidated Ashcroft Hancock Co., Inc.
Bristol Company.

Mercury-Column Vacuum Gages

**Taylor Instrument Co.*

Draft Gages

Hays Corp.

Indicating and Recording Temperature Instruments

Leeds and Northrup Co.
Taylor Instrument Co.
Consolidated Ashcroft Hancock Co., Inc.
General Electric Co.
C. J. Tagliabue Mfg. Co.

Flow Meters

Bailey Meter Co.
Builders Iron Foundry.

Steam Flow-Air Flow Meters

Bailey Meter Co.

Water Level

Diamond Power Specialty Corp.
Crane Co.
The Liquidometer Corp.
Bailey Meter Co.

Stoker Tachometers

The Electric Tachometer Corp.

Turbine Signal System

Electric Indicator Corp.

Superheater Damper-Position Indicators

General Electric Selsyn Motors
The Detroit Edison Co.

ESSEX SWITCHING STATION

Circuit Breakers

Type FH-209-C, 600- and 3000-amp, 35-kv circuit-breakers, 40,000-amp interrupting capacity, solenoid-operated, each phase inclosed in metal housing.—*General Electric Co.*
Deion breakers, same rating.—*Westinghouse Elec. & Mfg. Co.*

Equalizer Reactors

Indoor dry type, 1080 kva, 1200 amp, 24-kv circuit voltage, each phase inclosed in metal case.—*Metropolitan Device Corp.*

Main Bus

Two 2-in. double-extra-heavy copper tubes per phase, rated 2700 amp at 35 C rise, each phase inclosed in metal housing.

Equalizer Bus

Two 4-in. aluminum channels per phase, rated 2100 amp at 35 C rise, each phase inclosed in metal housing.

Breaker and Bus Housings

Aluminum for heavy currents, steel for light currents, sectionalized and insulated from building and from adjacent sections.

Relays

For Bus-Fault Protection—Instantaneous, overcurrent type PQ 29Y2.—*General Electric Co.*
For Generator Differential Protection—Ratio-differential, type CA.—*Westinghouse Elec. & Mfg. Co.*
Instantaneous, overcurrent type PQ—*General Electric Co.*
For Parallel-Feeder Protection—Balanced-current type PD 3 Time-delay, overcurrent type PQ 1 Y2.—*General Electric Co.*
For Radial-Feeder Protection—Combined instantaneous and inverse time, type RI.—*Condit Electrical Mfg. Co.*

Control Wiring

Armored lead-covered multiple-conductor control cable, mounted on racks in runway.—*The Okonite Company.*

Switchboard

Steel cabinet type, benchboard style for generator and section-breaker controls, panel type for feeder control and relays.

Test Equipment

150-kv Kenetron cable-testing set with distribution system.
General Electric Co.

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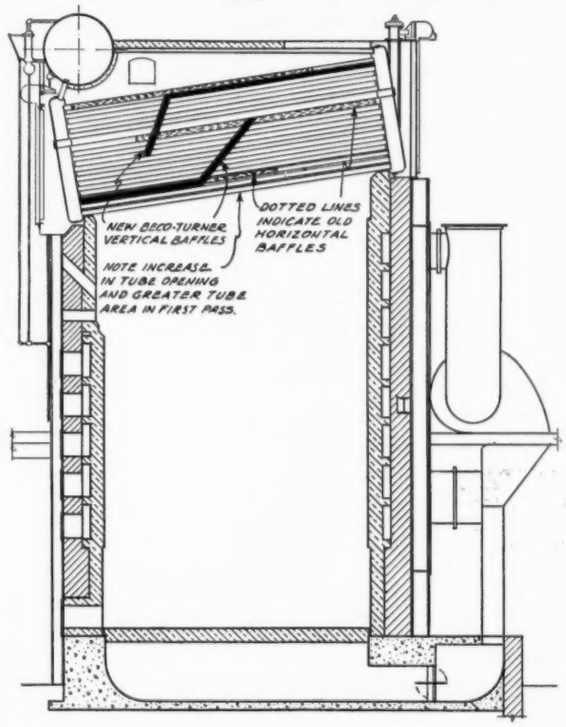
NEW BECO-TURNER VERTICAL BAFFLES
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3. **Furnace maintenance decreased.** Excessive deterioration of furnace walls overcome by "opening up" the boiler, eliminating former point of constriction.
4. **Improved boiler operation.** This boiler now steams easier and develops an increased rating. Fuel consumption reduced.

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PENNSYLVANIA BITUMINOUS COALS—II

Medium- and Low-Volatile Coals

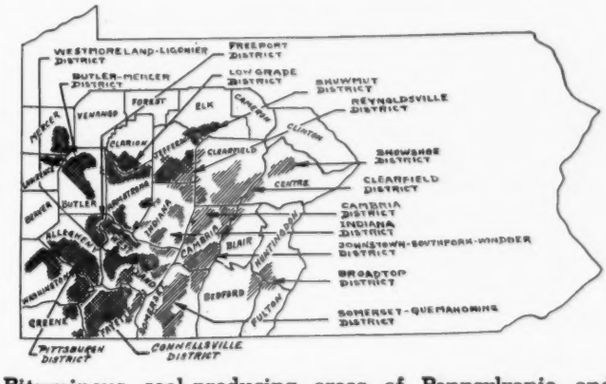
In the April issue the author dealt with the classification and analyses of high-volatile Pennsylvania coals whereas the present article discusses the medium- and low-volatile coals produced in that state. To date the series has covered Ohio, Kentucky, Virginia, Illinois, Indiana and Pennsylvania bituminous coals. West Virginia and Tennessee coals will be taken up in subsequent articles.

By P. B. PLACE

Combustion Engineering Company, Inc.

MEDIUM- and low-volatile coals containing 14 to 31 per cent volatile matter on a moisture- and ash-free basis, are found in the eastern half of the bituminous area shown on the accompanying map. The bulk of the low-volatile coals, having a volatile range of 14 to 23 per cent comes from Cambria, Somerset and Clearfield counties and from the Broad Top district of Bedford, Huntingdon and Fulton counties. The medium-volatile coals, containing 23 to 31 per cent volatile, are mined chiefly in Indiana, Fayette and Westmoreland counties. Other counties of less productive importance in this area, are Centre, Clinton, Cameron and Tioga. The coals from Clearfield county are mostly on the border line between low and medium volatile and those of Indiana are similarly on the border line between medium and high volatile. Though the bulk of the production from Cambria and Somerset counties is classed as low volatile, some medium-volatile coal is also produced.

Typical low-volatile districts are the Broad Top, the Johnstown, South Fork and Black Lick in Cambria county, the Windber and Quemahoning in Somerset county and the Moshannon in Clearfield county. Standard bunker coals, having a high heat value, low moisture and low ash content and a volatile of 15 to 20 per cent, are found in these and adjacent districts.



Bituminous coal-producing areas of Pennsylvania and principal mining districts

The Salt Lick and Confluence districts in Fayette county, the Ligonier district in Westmoreland county, the Turkeyfoot district in Somerset county, the Barnesboro and Gallitzin districts in Cambria county and the Black Lick and Mahoning districts in Indiana county are typical medium-volatile districts.

Both the medium- and low-volatile coals of central Pennsylvania are soft and may be easily crushed to small particles. A large proportion of fines and slack is produced during mining operations and much of the coal is sold and shipped as "run of mine" because of the difficulty in sizing it. These coals are also subject to weathering. The low-volatile coals are softer than the medium-volatile and are generally known as smokeless fuels.

These coals may be efficiently burned on underfeed stokers or in pulverized form. The medium-volatile fuels are particularly adaptable to firing in pulverized form, being easy to pulverize and containing sufficient volatile matter to stabilize combustion. The moisture in the coals generally runs between two and four per cent, though Broad Top coals often contain less than two per cent. The ash content varies considerably but is usually between six and ten per cent. The fusion temperature of the ash of the medium-volatile coals may be classed as between 2200 and 2600 and that of the low-volatile coals as above 2500.

Table VII gives typical individual analyses of medium- and low-volatile coals from the principal seams and counties. Practically all of the production from this area is from the Freeport and Kittanning seams of the Allegheny group. The variation in composition of some of the seams within a single county is considerable, particularly in Cambria and Somerset counties. The typical analyses are assembled in more than one group of similar volatile content where necessary to represent correctly the whole county. The moisture and ash values in the table are on an "as-received" basis and other values are "moisture- and ash-free," and indicate the general range in the items of the complete analysis.

Table VIII gives average analyses of various seams in the principal counties in this area. The seams are listed roughly in the order of their importance in each county and the counties are listed in the order of their importance on a production basis.

These tables serve as references from which a representative analysis may be selected and converted to an "as-received" basis for any known or selected moisture

TABLE VII

TYPICAL INDIVIDUAL ANALYSES OF MEDIUM AND LOW VOLATILE BITUMINOUS COALS IN THE PRINCIPAL PRODUCING COUNTIES

I. UPPER FREEPORT COAL

As Received				Moisture and Ash Free					
Moisture	Ash	Volatile Matter	Fixed Carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu/lb
Indiana County - East, North and Center									
1.9	7.4	27.4	72.6	1.1	5.2	88.3	1.9	3.5	15,530
3.3	8.1	29.6	70.4	2.5	5.3	87.0	1.6	3.6	15,550
1.0	9.1	29.0	71.0	3.0	5.1	86.9	1.2	3.8	15,520
Indiana County - West and South									
2.1	9.2	32.4	67.6	1.8	5.3	86.5	1.6	4.8	15,370
2.3	10.2	31.5	68.5	2.6	5.3	86.4	1.5	4.2	15,400
Westmoreland County - Ligonier District - East									
2.3	7.5	29.3	70.7	3.6	5.1	86.4	1.7	3.2	15,450
2.9	11.0	29.9	70.1	1.8	5.2	87.0	1.4	4.6	15,380
3.0	8.2	27.7	72.3	1.1	5.3	87.6	1.4	4.6	15,490
Somerset County									
1.4	11.6	21.3	78.7	2.2	4.9	88.9	1.9	2.1	15,640
3.2	11.2	23.9	76.1	2.0	5.1	87.8	1.5	3.6	15,500
3.1	10.9	22.0	78.0	1.8	5.0	88.8	1.5	2.9	15,590
Cambria County - Johnstown-South Fork District - South and West									
2.8	11.3	18.2	81.8	2.8	4.6	89.0	1.4	2.2	15,670
3.3	6.4	20.2	79.8	2.0	4.8	89.4	1.6	2.2	15,700
4.1	7.0	21.4	78.6	2.5	4.9	89.0	1.6	2.0	15,700
Cambria County - Barnesboro-Patten District - North and West									
2.6	8.0	24.3	75.7	2.3	5.4	87.9	1.4	3.0	15,700
1.5	7.2	25.6	74.4	0.9	5.1	88.8	1.5	3.7	15,640
3.0	8.4	25.8	74.2	1.8	5.3	87.9	1.5	3.5	15,690
Cambria County - Portage-Gallitzin District - East									
3.3	9.9	27.7	72.8	2.1	5.3	88.5	1.4	2.7	15,690
2.7	6.2	28.6	71.4	1.5	5.1	88.2	1.6	3.6	15,670
2.7	8.9	28.2	71.8	0.9	5.2	88.3	1.4	4.2	15,640
Fayette County - Central and South									
2.7	14.1	33.8	66.2	4.5	5.3	84.5	1.5	4.2	15,110
2.1	16.4	30.5	69.5	4.1	5.3	85.4	1.5	3.7	15,300
Bedford County - Broad Top District									
1.2	11.6	18.8	81.2	2.2	4.7	89.1	1.6	2.4	15,610
1.6	12.1	18.9	81.1	2.3	4.5	89.2	1.7	2.3	15,540

II. LOWER FREEPORT COAL

Clearfield County - South and East									
2.9	4.6	22.5	77.5	0.8	5.1	89.5	1.5	3.1	15,700
3.2	6.5	23.5	76.5	0.8	5.0	88.4	1.5	4.3	15,570
Clearfield County - Central									
4.1	6.1	26.0	74.0	2.1	5.3	87.4	1.2	4.0	15,600
2.9	7.5	28.1	71.9	2.4	5.2	87.9	1.5	3.0	15,630
Cambria County									
3.1	6.5	24.9	75.1	1.8	5.2	88.9	1.4	2.7	15,670
2.8	9.0	24.0	76.0	2.1	5.2	88.2	1.5	3.0	15,600
1.8	7.4	23.9	76.1	2.0	5.0	88.4	1.5	3.1	15,660
Somerset County									
2.7	11.3	22.1	77.9	1.2	5.0	89.2	1.6	3.0	15,510
0.9	8.0	18.9	81.1	0.8	4.8	89.7	1.5	3.2	15,750
2.9	5.2	20.4	79.6	0.7	4.9	90.2	1.5	2.7	15,620

III. UPPER KITTANNING COAL

Somerset County - North									
1.2	8.5	17.2	82.8	0.8	4.7	89.9	1.6	3.0	15,700
1.3	8.0	16.5	83.6	0.7	4.6	89.9	1.5	3.3	15,660
Somerset County - Central									
2.4	9.0	19.5	80.5	2.9	4.5	88.6	1.4	2.6	15,500
3.6	9.3	20.2	79.8	1.9	4.8	89.2	1.4	2.7	15,520
Somerset County - South Central									
3.4	9.5	23.7	76.3	1.5	4.8	88.7	2.0	3.0	15,630
2.5	12.1	24.2	75.8	2.7	5.0	88.5	1.5	2.3	15,560
Somerset County - South									
2.3	12.2	28.3	71.7	4.7	5.2	85.8	1.5	2.8	15,390
2.4	12.4	27.2	72.8	4.2	5.1	86.4	1.4	2.9	15,440
Fayette County - South East									
2.6	8.8	27.3	72.7	2.5	5.0	87.9	1.5	3.1	15,560
3.1	6.8	28.7	71.3	2.1	5.3	87.3	1.6	3.8	15,540

TABLE VII (Continued)

Cambria County - South									
3.3	7.6	14.0	86.0	2.2	4.5	89.4	1.5	2.4	15,780
1.3	8.8	16.3	83.7	1.8	4.6	90.4	1.6	1.6	15,630
3.7	10.1	16.8	83.2	2.7	4.6	89.5	1.4	1.8	15,590
Clearfield County									
3.2	7.5	26.5	73.5	4.2	5.1	86.9	1.4	2.4	15,600

IV. MIDDLE KITTANNING COAL

Clearfield County									
2.7	10.2	23.0	77.0	2.3	5.2	88.2	1.4	2.9	15,610
3.9	8.8	22.7	77.4	1.2	5.1	88.7	1.5	3.5	15,590
2.8	10.0	23.3	76.7	1.5	5.0	88.3	1.4	3.8	15,650

V. LOWER KITTANNING COAL

Cambria County - Windber District - South East									
2.8	7.8	15.5	84.5	1.5	4.6	89.8	1.4	2.7	15,800
2.9	7.3	14.0	86.0	1.5	4.4	89.3	1.5	3.3	15,780
3.0	7.9	14.5	85.5	1.3	4.7	89.6	1.5	2.6	15,810
Cambria County - Johnstown-South Fork District - South Central									
3.1	6.1	19.1	80.9	1.2	4.9	90.6	1.4	1.9	15,760
3.6	6.5	20.7	79.3	2.2	5.0	89.7	1.4	1.7	15,720
3.5	6.8	20.0	80.0	2.5	4.9	89.3	1.3	2.0	15,770
Cambria County - Barnesboro-Patten District - North West									
0.8	7.2	24.9	75.1	2.2	5.0	88.7	1.3	2.8	15,700
3.9	5.9	25.1	74.9	0.7	5.3	88.6	1.4	4.0	15,760
0.9	6.7	25.0	75.0	1.4	5.1	88.4	1.4	3.7	15,680
Cambria County - Gallitzin-Cresson District - East Central									
0.8	9.1	26.6	73.4	1.5	5.1	87.9	1.4	4.1	15,590
2.0	8.2	24.6	75.4	0.8	5.0	88.1	1.5	4.6	15,460
Somerset County - Windber District - North East									
2.5	7.0	15.5	84.5	1.4	4.5	90.2	1.4	2.5	15,760
4.2	4.5	14.0	86.0	1.1	4.4	90.5	1.4	2.6	15,800
2.5	6.2	13.5	86.5	1.2	4.5	90.0	1.5	2.8	15,740
Somerset County - Quemahoning District - Central									
2.0	8.2	18.5	81.5	2.7	4.6	89.3	1.4	2.0	15,700
2.5	7.7	18.4	81.6	2.6	4.7	89.6	1.4	1.7	15,720
1.0	10.4	18.1	81.9	2.5	4.7	89.4	1.4	2.0	15,680
Somerset County - Turkeyfoot District - South									
2.9	13.3	25.1	74.9	3.2	5.2	87.3	1.3	3.0	15,420
3.7	9.6	23.2	76.8	2.6	5.0	88.1	1.4	2.9	15,550
2.7	12.5	23.7	76.3	3.3	4.9	86.8	1.5	3.5	15,390
Indiana County									
3.0	8.3	28.7	71.3	3.7	5.2	86.2	1.5	3.4	15,510
2.3	8.4	27.7	72.3	3.2	5.2	87.3	1.5	2.8	15,530
Centre County									
3.9	8.2	27.5	72.5	2.3	5.2	87.5	1.6	3.4	15,510
3.0	6.7	25.4	74.6	1.7	5.1	88.1	1.5	3.6	15,660
5.4	9.2	24.4	75.6	3.0	5.1	87.6	1.5	2.8	15,540
Clearfield County									
3.6	8.5	23.7	76.3	3.9	5.1	87.7	1.5	1.8	15,720
0.9	9.0	24.0	76.0	2.2	5.0	88.2	1.5	3.1	15,610
Fayette County									
2.2	16.1	32.9	67.1	4.1	5.5	84.6	1.5	4.3	15,270
3.0	11.7	28.3	71.7	4.7	5.1	85.6	1.1	3.5	15,420
Bedford County - Broad Top District									
1.7	5.9	18.0	82.0	1.6	4.6	90.3	1.4	2.1	15,680
1.3	6.7	19.3	80.7	1.6	4.6	89.9	1.5	2.4	15,700
Huntingdon County - Broad Top District									
2.1	6.4	16.9	83.1	1.2	4.6	90.6	1.4	2.2	15,830
2.2	6.1	15.3	84.7	1.3	4.6	90.9	1.4	1.8	15,870

VI. BROOKVILLE COAL

Centre, Clarion, Clearfield and Clinton Counties									
3.3	11.3	24.8	75.2	2.7	5.0	87.2	1.3	3.8	15,380
1.9	9.8	25.0	75.0	2.2	5.1	88.5	1.3	2.9	15,590
2.3	8.6	24.4	75.6	3.0	4.9	87.7	1.4	3.0	15,555
2.7	16.2	25.1	74.9	0.8	4.9	87.7	1.4	5.2	15,300

VII. CLARION COAL

Huntingdon County - Broad Top District									
1.7	8.6	19.5	80.5	1.7	4.9	89.9	1.5	2.0	15,680
Fayette County									
2.5	13.6	28.7	71.3	6.0	5.2	84.9	1.4	2.5	15,290

TABLE VIII

AVERAGE ANALYSES OF MEDIUM AND LOW VOLATILE COALS FROM THE PRINCIPAL SEAMS AND COUNTIES

As Received, per cent				Moisture and Ash Free, per cent					
Moisture	Ash	Volatile Matter	Fixed Carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu/lb
Cambria County									
Lower Kittanning Seam									
2-3	7-8	14.7	85.3	1.4	4.6	89.6	1.5	2.9	15,795
2-4	5-9	16.3	83.7	1.7	4.5	89.7	1.3	2.8	15,705
3-4	5-7	19.9	80.1	2.0	4.9	89.9	1.4	1.8	15,750
1-4	5-8	25.0	75.0	1.4	5.1	88.6	1.4	3.5	15,710
Upper Kittanning Seam									
1-4	7-11	15.7	84.3	2.2	4.6	89.8	1.5	1.9	15,670
Upper Freeport Seam									
2-5	6-12	19.9	80.1	2.4	4.8	89.1	1.5	2.2	15,690
1-3	7-9	25.2	74.8	1.7	5.3	88.2	1.5	3.3	15,675
2-4	6-10	28.2	71.8	1.5	5.2	88.3	1.5	2.2	15,675
Lower Freeport Seam									
1-4	6-9	24.3	75.7	2.0	5.1	88.5	1.5	2.9	15,645
Fayette County									
Lower Kittanning Seam									
2-3	11-17	30.6	69.4	4.4	5.3	85.1	1.3	3.9	15,345
Upper Kittanning Seam									
2-4	6-9	28.0	72.0	2.3	5.2	87.6	1.5	3.4	15,550
Clarion Seam									
2-3	13-14	28.7	71.3	6.0	5.2	84.9	1.4	2.5	15,290
Westmoreland County									
Upper Freeport Seam									
2-3	7-11	29.0	71.0	2.2	5.2	87.0	1.5	4.1	15,440
Somerset County									
Upper Kittanning Seam									
1-2	8-9	16.8	83.2	0.8	4.6	89.9	1.5	3.2	15,680
2-4	9-10	19.9	80.1	2.4	4.6	88.9	1.4	2.7	15,510
2-4	9-13	24.0	76.0	2.1	4.9	88.6	1.7	2.7	15,595
2-3	12-13	27.8	72.2	4.4	5.1	86.1	1.5	2.9	15,415
Lower Kittanning Seam									
2-5	4-8	14.3	85.7	1.2	4.5	90.2	1.4	2.7	15,765
1-3	7-11	18.3	81.7	2.6	4.7	89.2	1.4	1.9	15,700
2-4	9-14	24.0	76.0	3.0	5.0	87.4	1.4	3.2	15,450
Upper Freeport Seam									
1-4	10-12	22.4	77.6	2.0	5.0	88.5	1.6	2.9	15,575
Lower Freeport Seam									
1-3	5-12	20.5	79.5	0.9	4.9	89.7	1.5	3.0	15,625
Indiana County									
Upper Freeport Seam									
1-4	7-10	28.7	71.3	2.2	5.2	87.4	1.6	3.6	15,530
2-3	6-11	32.7	67.3	1.8	5.3	86.3	1.6	5.0	15,360
Lower Kittanning Seam									
2-3	8-9	28.2	71.8	3.4	5.2	86.8	1.5	3.1	15,520
Clearfield County									
Lower Freeport Seam									
2-4	4-7	23.0	77.0	0.8	5.0	89.0	1.5	3.7	15,635
2-5	6-8	27.0	73.0	2.2	5.2	87.7	1.4	3.5	15,615
Lower Kittanning Seam									
1-4	8-9	23.8	76.2	3.0	5.1	88.0	1.5	2.4	15,665
Middle Kittanning Seam									
1-4	8-11	23.0	77.0	1.7	5.1	88.4	1.5	3.3	15,615
Upper Kittanning Seam									
3-4	7-8	26.5	73.5	4.2	5.1	86.9	1.4	2.4	15,600
Brookville Seam									
2-3	8-9	24.4	75.6	3.0	4.9	87.7	1.4	3.0	15,555
Clarion County									
Brookville Seam									
1-3	9-10	25.0	75.0	2.2	5.1	88.5	1.3	2.9	15,590
Bedford and Huntingdon Counties Broad Top District									
Upper Freeport or Kelly Seam									
1-3	11-13	18.8	81.2	2.2	4.6	89.2	1.6	2.4	15,575
Lower Kittanning or Barnett Seam									
1-3	5-7	17.3	82.7	1.5	4.6	90.4	1.5	2.0	15,770
Clarion or Fulton Seam									
1-3	8-9	19.5	80.5	1.7	4.9	89.9	1.5	2.0	15,680

TABLE IX

AVERAGE ANALYSIS OF MEDIUM VOLATILE COAL FROM INDIANA, CAMBRIA, CLEARFIELD AND WESTMORELAND COUNTIES

	As Received	Dry or Moisture Free	Moisture and Ash Free
Moisture	3.0	-	-
Ash	8.0	8.25	-
Volatile Matter	24.92	25.69	28.0
Fixed Carbon	64.08	66.06	72.0
	100.00	100.00	100.0
Sulphur	1.96	2.02	2.2
Hydrogen	4.63	4.77	5.2
Carbon	77.87	80.28	87.5
Nitrogen	1.34	1.38	1.5
Oxygen	3.20	3.30	3.6
	89.00	91.75	100.0
Heat Value Btu/lb	13850	14275	15560

TABLE X

AVERAGE ANALYSIS FOR A LOW VOLATILE COAL FROM BROADTOP DISTRICT (HUNTINGDON, BEDFORD & FULTON COUNTIES)

	As Received	Dry or Moisture Free	Moisture and Ash Free
Moisture	2.0	-	-
Ash	10.0	10.20	-
Volatile Matter	16.28	16.61	18.5
Fixed Carbon	71.72	73.19	81.5
	100.00	100.00	100.0
Sulphur	1.58	1.62	1.8
Hydrogen	4.13	4.22	4.7
Carbon	79.03	80.64	89.8
Nitrogen	1.32	1.35	1.5
Oxygen	1.94	1.97	2.2
	88.00	89.80	100.0
Heat Value Btu/lb	13795	14075	15675

and ash content. Given analyses may be checked by converting them to a "moisture- and ash-free" basis and checking them against an average analysis for the same seam and county. The method of converting analyses to a desired basis is given in previous articles of this series on coal and may be found in most fuel handbooks. For more general purposes, average analyses for medium- and low-volatile coals are given in Tables IX and X, calculated to "as-received," "dry" and "moisture- and ash-free" basis.

In many of the coal-producing states, the "moisture- and ash-free" composition of the coal is very constant over a wide area and often a single average analysis will fairly represent the output of several counties and seams. In the Pennsylvania bituminous area, however, there is considerable variation in the analyses of coals even within a limited area and it is difficult to select a single analysis that represents a single seam or county. For specific purposes, where accuracy is desired, the coal in question should be carefully sampled and analyzed by a competent coal chemist. For general purposes, however, and for most engineering calculations based on assumed conditions, a more reliable average analysis may be found in these Tables than in the usual list of typical coal analyses.

The classification of bituminous coals into high-, medium- and low-volatile groups is, as indicated in the names, based on the amount of volatile matter in the coal. The American Society for Testing Materials has recently sponsored such a classification that divides the groups arbitrarily as follows:

High-volatile	Over 31 per cent volatile (m & a free)
Medium-volatile	23 to 31 per cent volatile
Low-volatile	14 to 23 per cent volatile

Although in this article the above division has been generally followed in grouping the coals, the variation in volatile through the bituminous area is spread over the whole range from 14 to 44 per cent and sharp differentiation between the groups is more a matter of arithmetic than of inherent properties of the coal.

In Table XI are given average analyses for Pennsylvania coals when arranged in groups having a volatile content of plus or minus one to two per cent from the given average. For example, averaging a number of coal analyses having a volatile range of 14.5 per cent to 17.0 per cent gave an average volatile of 15.6 per cent. Arranged in order of increasing volatile content it is interesting to note the consistent variation in the other items of the complete analyses. The sulphur hydrogen, nitrogen and oxygen increase with increase in volatile matter and the fixed carbon, total carbon and heat value decrease with increase in volatile matter.

This table serves as a basis for setting up an average analysis for a Pennsylvania bituminous coal for a known or desired volatile content when the source of the coal is not involved. A moisture and ash content must be known or assumed to convert the average analysis in the table to an "as-received" basis.

A useful relationship is expressed in the following equation which is found to hold within a half of one per cent for the bulk of Pennsylvania bituminous coals:

$$\frac{\text{Btu per lb}}{S + H + C} = K - S$$

where the Btu per lb, and S, H and C are "moisture- and ash-free" values for the heat value and percentages of sulphur, hydrogen and carbon, respectively, in the ultimate analysis. For general purposes, K may be taken as 166.0 but for closer calculations, K is 166.5 for high-volatile coals, 166.0 for medium-volatile coals and 165.5 for low-volatile coals. Thus, for example, applying the above equation to the Upper Freeport coal from Westmoreland county listed in Table VIII we check the heat value to within 25 Btu as follows:

$$(166.0 - 2.2)\,(2.2 + 5.2 + 87.0) = 15463 \text{ Btu.}$$

TABLE XI

AVERAGE ANALYSES OF PENNSYLVANIA BITUMINOUS COALS ARRANGED IN ORDER OF INCREASING VOLATILE MATTER MOISTURE AND ASH FREE

Volatile Matter	Fixed Carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu/lb
15.6	84.4	1.5	4.6	89.8	1.4	2.7	15,725
19.3	80.7	2.0	4.8	89.5	1.4	2.3	15,660
23.9	76.1	2.1	5.0	88.4	1.5	3.0	15,600
27.9	72.1	2.8	5.2	87.2	1.5	3.3	15,545
32.3	67.7	2.8	5.3	86.0	1.5	4.4	15,370
36.6	63.4	2.0	5.5	85.1	1.6	5.8	15,235
39.1	60.9	2.5	5.6	83.9	1.6	6.4	15,090
42.2	57.8	3.9	5.7	82.3	1.6	6.5	14,930

NEW CATALOGS AND BULLETINS

Any of these publications will be sent on request.

Blowoff Valves

The Edward Valve & Mfg. Co., Inc., East Chicago, Ind., has issued Catalog No. 11-D covering its line of blowoff valves. In addition to descriptions of four series of blowoff valves, in Ferac metal, cast-steel, and forged-steel, both globe and angle types, for all American Standard pressures, it contains many illustrations of actual installations and optional piping arrangements. A table of secondary pressure ratings for steel valves on boiler-water lines below the water line gives service values complying with recent A.S.M.E. Boiler Code rulings.

Coal Conveying

Stephens-Adamson Mfg. Co., Aurora, Ill., has issued a 36-page catalog describing its line of equipment for conveying coal and various bulk materials. The description matter is supplemented by charts and useful tables giving data applicable to the handling of different materials.

Combustion Recorders

Catalog RA-346 of The Hays Corporation, Michigan City, Indiana, describes the operation and construction of its line of CO_2 draft and temperature recorders and indicating instruments. Data on their application are included.

Condensate-Return Pumps

The Cameron "Motorpump," with its automatic starting and stopping devices, for handling condensate returns is described in a recent bulletin by Ingersoll-Rand Company, New York. Installation views, plans and specifications and tables of sizes are included.

Hot Lime-Soda Water Softening

Engineers will find much that is informative in a 48-page booklet prepared by the staff of The Permutit Company, New York, discussing the hot lime-soda process of water softening. The functions of the various components of such a system are clearly described and the booklet is profusely illustrated by diagrams, cut-away wash drawings and photographs. An appendix contains specifications for a standard hot lime-soda plant, tables of the quantities of chemicals required, chemical reactions involved and data on pumping and friction in pipes.

Instruments

"Instruments from the Executive Viewpoint" is the title of a very attractive 24-page booklet being distributed by the Brown Instrument Company, Philadelphia. The subject is discussed chiefly from the economic angle and covers instruments used in industrial operations as well as those for power plants.

Orifice Meters

Bulletin No. 2092 of the Cochrane Corporation, Philadelphia describes its new orifice meter for measuring the flow of steam, air, gas and fluids through pipe lines. It is made in the recording and integrating types in ten classes applicable to various pressure differentials.

Refractories

"Standard Handbook of Refractories" is the title of a 52-page booklet issued by the Standard Fuel Engineering Co., Detroit, containing information on refractory cements, firebrick, furnaces and refractory materials. Useful tables are included.

Seamless Tubing

"Globe Seamless Tubing for Safety" is the title of a new folder issued by Globe Steel Tubes Company, Milwaukee, which emphasizes the fact that such tubing is safer, because there are no seams or welds and no potential weak points along the line of a weld, which might give a starting place for costly failure. The folder also outlines other reasons why this tubing conforms with today's higher standards of safety.

Soot Blowers

A 40-page illustrated catalog just off the press is devoted to automatic valved soot blowers as manufactured by the Diamond Power Specialty Corporation, Detroit. Soot blower materials to withstand the severe conditions imposed are discussed, and soot-blowers with steel, calorized and Dialoy elements, for different temperature ranges, are described. Installation drawings are included as well as data on fuel loss resulting from various thicknesses of soot deposit. Additional Diamond products such as water columns and gages, high- and low-water alarms and smoke indicators are described and illustrated.

Steam Engines

A line of steam engines for driving fans, stokers, compressors, generating sets up to 150 kw and special drives for steam pressures up to 250 lb is completely covered in a 48-page catalog of the Troy Engine & Machine Co., Troy, Pa. These engines are built in both the vertical and the horizontal types, water rates for the various sizes and steam conditions are included as well as dimensions and detailed specifications. A list of installations shows the wide variety of uses and many industries in which these engines are used.

Thermometers

The Bristol Company, Waterbury, Conn., has issued a new thermometer catalog, containing 88 pages of information concerning the theory and practice of modern-day thermometry. This catalog, No. 1250, covers liquid-filled, vapor-tension, and gas-filled recording, indicating and controlling thermometers. It also describes a new small-bulk gas-filled thermometer. In connection with automatic temperature controllers, it gives information regarding both the electric and pneumatic types, and helpful sketches to illustrate how they are applied. Over 500 temperature recording charts are illustrated in full size.

Turbine-Generator Sets

D-C turbine-generator sets of from 10 to 400 kw are described, and their operating advantages enumerated, in a new four-page folder, published by the General Electric Company, Schenectady, N. Y.

Valve Material Specifications

Service requirements for high temperatures and high pressures form the major theme of a new 20-page bulletin issued by The Edward Valve & Mfg. Company, Inc., East Chicago, Ind. It is entitled "Valve Material Specifications and Standards" and contains chemical analyses and physical rejection limits of applicable specifications of recognized standing with annotations as to uses, limitations and variations from basic standards. There are also discussed alloying elements, heat treatment, corrosion resistance and high temperature service. Dimensional standards are included.

Valves

A twenty-page booklet describing the line of Hancock forged-steel valves for steam pressures up to 1500 lb per sq in. has just been issued by the Consolidated Ashcroft Hancock Company, Bridgeport, Conn. Dimensional material specifications and weights as well as price lists for each pressure range and size are included.

Water Columns

An eight-page folder has just been issued by The Reliance Gauge Column Company, Cleveland, O., describing and giving complete information on its float-operated safety water columns. Size and price lists are included as well as specifications for fittings and installation instructions. It also contains the A.S.M.E. Requirements for water glasses and gage cocks.

Value of Proper Furnace Equipment to Power Plant Economy*

By M. K. DREWRY

Milwaukee Electric Railway and Light Co.

Contending that the furnace is the starting point in search for economy, the author discusses the numerous variables involved such as excess air, the effect of furnace temperature on efficiency, superheat behavior as affected by furnace conditions, radiant heat absorption and a comparison of the dry bottom and slagging types. One conclusion of his study is that furnace temperatures higher than 2000 F are more likely to decrease than to increase combustion efficiency.

THE definite trend toward large high-pressure boiler units, planned for nearly continuous operation, emphasizes the necessity of furnace equipment that can operate almost indefinitely without outages.

"What stops boiler-units" is a question receiving much attention at present, because operators realize that economy is often most affected by unavailability of otherwise inherently efficient equipment. The need of periodic furnace cleanings, occurrence of water-wall failures, or replacement of stoker parts, for instance, can subtract as much from integrated savings of new equipment as the failure to attain expected high temperatures or inherently high efficiencies.

Someone has said that new boiler units should be idle only once a year, and then only for inspection. Were this an actuality, important savings could be made in first costs and operating expenses by making extensions with single large units.

That boiler units can almost attain the afore-mentioned specification of one stop per year is indicated by the following five-year data of four large high-pressure boilers operating at high load factor. In their case, system load was not sufficient to permit continuous operation, but it did require their operation every week day. Their use of reheat, coupled with starting and stopping the equivalent of every other night because of low system loads, perhaps makes their record as distinctive as though they operated continuously.

AVAILABILITY DATA OF 4 LARGE HIGH-PRESSURE BOILER UNITS FOR 5 YEARS

Per cent of elapsed time operated	76.1
Idle time (no load), per cent	7.0
Banked time, per cent	11.4
Times banked per month, average	17
Repair time, per cent	5.5
Availability, per cent	94.5

Experience proves that at least three of the units can be operated indefinitely without outages in any way caused by furnace equipment. In the earliest unit, ash forms on inaccessible brickwork in furnace corners when using mid-western coal. In none, is slagging of the boiler tubes scarcely more than incidental when burning various mixtures of Western Kentucky and Illinois Coals with 2050 to 2200 F ash-fusion temperatures, with 22 per cent excess air.

The furnace of a similar, but larger, unit after 114 days of continuous operation when burning 2250 F ash fusion coal with 15 per cent excess air, without any cleaning before outage, showed some fragile deposits recognizable on the water- and steam-cooled surfaces, but the boiler tubes were positively free of even fragile ash. Four consecutive months of initial operation of the station in which this boiler is installed has averaged 11,412 Btu per kwhr net. Both superheat and reheat temperatures are practically constant at 820 F throughout a load range of 20,000 to 80,000 kw in spite of reheater inlet steam (from the turbine) coincidently increasing 100 F. The furnace design contributes appreciably to this economy.

Experience with these units proves that a real basis exists for permitting the selection of large, single, boiler units, and that furnace equipment is now available that keeps new, efficient equipment in service to attain maximum economy.

Excess Air Reduction Possibilities

Seventeen per cent CO_2, corresponding with approximately 10 per cent excess air, has often been observed in pulverized-coal installations without presence of CO. Many boiler units are now operating with 15 per cent excess air (about 16 per cent CO_2). Ten per cent excess air average seems practical for those units in which air leakage is limited to a few per cent.

Use of large air heaters has prompted curtailment of air leakage, because air heater performance suffers rapidly from cooling-air shortages. In one case, 10 per cent less air through the heater increases flue gas temperatures 30 deg, thus causing nearly one per cent additional stack loss, plus another loss of similar magnitude if leakage air is of no assistance in the combustion process. Ten per cent total air leakage has been averaged by four large units for several years. Another more re-

* Presented at the Midwest Power Engineering Conference, Chicago, April 23, 1936.

cent unit experiences less than 5 per cent air leakage. Making modern units practically pressure-tight will assist in attaining the next goal of 10 per cent excess air.

Effect of Furnace Temperature upon Combustion Efficiency

That temperature differences of pulverized fuel-fired furnaces have slight effect upon combustion rate is deduced from a comprehensive research study of carbon combustion rates by Messrs. Tu, Davis and Hottel.[1] They conclude:

"In the temperature range in which diffusion controls (above approximately 1500 F they indicate elsewhere) the rate of combustion varies approximately as $T^{0.6}$ to $T^{1.1}$."

Thus, the combustion rate scarcely increases proportionately with temperature in actual furnaces. Considering that time for combustion varies inversely with temperature (due to higher specific volume of furnace gases) the conclusion can be drawn that in typical furnaces, combustion completeness is approximately independent of temperature. *Higher temperatures than 2000 F are more likely to decrease combustion efficiency than to increase it.*

Other Variables Affecting Combustion Rapidity

The following additional conclusions by Messrs. Tu, Davis and Hottel on the fundamentals of combustion rates should receive attention in furnace design for best economy.

"In either of the regions in which diffusion or chemical reaction at the surface controls the combustion rate, the rate has been found to vary linearly with partial pressure of oxygen in the ambient medium. This is in agreement with the theory presented.

"In the temperature range in which chemical reaction controls, the rate of combustion doubles for every 27 deg F at 1430 F.

"The rate of combustion, in the temperature range in which diffusion controls, varies as the 0.4 to 0.7 power of the mass velocity, in substantial agreement with theory.

"The combustion rate, in absolute magnitude, lies as near as may be expected to the value predicted by the theory presented, since the predicted values depend on a questionable method of predicting film thickness.

"Evidence is presented which is interpreted by the authors as rendering untenable the hypothesis that combustion of carbon in air involves the transport of oxygen to the carbon surface in the form of carbon dioxide alone."

Superheat Temperature Uniformity

Because superheater duty is growing rapidly, and boiler duty is lessening almost as steadily, furnace equipment will play an increasingly important rôle in plant economy, and reliability as well.

The furnace is finally being recognized as responsible for much superheater misbehavior. Superheaters can no longer be considered as minor boiler auxiliaries and their performance simply a function of previous boiler-surface heat absorption. Furnace heat absorption is now a vital variable controlling maintenance of proper superheat temperatures.

Higher steam temperatures accentuate the need of more uniform steam temperature regulation, for bolting and other highly stressed parts become relatively weak. A 100 deg F temperature difference of component low-carbon steel parts causes stress of 20,000 lb per sq in. which added to initial stresses can cause leakage, shutdown and loss in economy. A steam pressure of 1200 lb requires 170 deg superheat for 750 F steam temperature, and twice as much for 920 F steam. Twenty per cent superheater performance change causes 46 deg F variation in the first case, but 84 deg F in the second, more serious, case. If 20 per cent variation is the maximum permissible at 750 F, 5 per cent variation, causing 20 deg fluctuation, represents equivalent desirable practice at 900 F. Thus, temperature control must improve greatly as higher temperatures are used.

In an extreme case of 1000 F, superheat and reheat, in connection with 1800-lb steam pressure and full usage of the regenerative cycle, superheater duty will become greater than boiler duty. It is interesting to imagine the enormity of steam temperature variations under those conditions were the use of present designs attempted. This exaggeration serves to indicate the underlying cause of some present-day problems, for it emphasizes inherent difficulties accruing from use of old designs for new conditions.

Variations in furnace heat absorption due to variable ash coatings on furnace tubes can affect plant economy adversely. Deposits for one load are unsatisfactory for another, and excess air requirements for one fuel can readily cause undesirable steam temperatures with another fuel. Proper thickness coatings are not built in an hour, or even a day, and are sometimes lost when banking or when overheating the furnace for slag-tapping under adverse circumstances. The operator must anticipate future load and fuel conditions, a procedure which often cannot be and is not done. Mixing of two or more different fuels to take advantage of existing coal markets will become increasingly difficult unless furnace equipment is carefully chosen.

Higher-alloy metals required for high steam temperatures usually have poorer heat transfer rates and higher thermal expansion rates than carbon steels. Castings are susceptible to cooling crack formation in the foundry, which cracks form convenient stress-concentration points in the field when the casting is subjected to steam-temperature changes. Failure causes large economy losses due to forced outages and resulting operation of old equipment, in addition to hazarding reliability and safety.

Could ash deposits be caused to form on the superheater tubes in the same proportions as on furnace and boiler tubes, economy losses would consist only of increased flue-gas heat losses. But ash deposits have the uncontrollable habit of forming in an infinite variety of patterns on boiler-unit equipment. Their control is impossible. It seems that a furnace design permitting minimum ash deposition in the furnace, on the first row of boiler tubes, or on the superheater tubes, is most nearly ideal.

Mechanical Regulation of Steam Temperature

De-superheating at all loads above half-load, adjusting superheater bypass baffles, and otherwise changing gas-flow rates appear temporary compromises when examined for their practicability in the future plant.

[1] *Industrial and Engineering Chemistry*, July 1934.

It seems obvious that when superheater duty equals boiler duty that surfaces of each must be similarly disposed in both the furnace and the convection bank. Under these conditions, regulation problems will be much easier of solution.

Radiant Superheaters

The use of radiant superheaters for high-steam temperatures will require modern rates of heat transfer. High-alloy tubes, with low-thermal conductance and high-thermal expansion are unfortunately poorer than carbon steel tubes in regard to heat-flow characteristics. They tend to warp when used on furnace walls, their welds fail unless well made and their total expansion presents structural problems. Transfer rates in excess of 75,000 Btu per hr per sq ft, corresponding to nearby furnace temperature of about 2300 F, are probably impractical. Decreasing superheater tube transfer with insulating surfaces also appears impractical, considering their variable insulating effect as they collect various thicknesses of ash coatings.

Dry Versus Wet Furnace Ash

Whether furnace temperatures should be above or below the ash melting point (which varies a few hundred degrees above the fusion temperature) appears a major question at present. What relative economy aspects have the two methods? The following tabulation catalogs their design and operating characteristics:

Furnace Type	Dry Ash	Molten Ash
Typical Average Temperature, F.	2100	2600
Furnace Design		
Size, relatively	Large	Small
Water walls	Bare	Insulated
Bottom	Hopper-type	Flat
Ash removal	Manually or hydraulicly	By tapping
Ash-storage space screened	Yes	No
Heat Transfer Rates to bare cooled surfaces, Btu/hr/sq ft	50,000	125,000
Per cent of Heat in Coal Absorbed in furnace	50	30
Ash Conditions		
At furnace bottom		
Normal outputs	Dry dust and small particles	Fluid
Low outputs	Dry dust	Solid
On furnace walls	Fragile accumulations	Thick lava-like fluid
At boiler entrance and superheater		
Normal outputs	Dry dust and fragile accumulations	Tenacious deposit
Low outputs	Dry dust	Fragile deposit
Superheat Temperature Regulation		
Effect of variable furnace cleanliness	Slight	Greater

Transition from the wet to the dry-ash state at various points in the furnace, boiler or superheating equipment, depending upon load, coal type, excess air, flame position and other variables, compared with maintenance of dry ash under all conditions, appears the important difference in the two furnace types.

Could this transition always faithfully occur in a large cooling space previous to the boiler entrance, then maintenance of uniform superheater temperatures would seem more practical. Of necessity this cooling space would be so large that size economy of the boiler unit would be largely lost.

Effective Radiant Heat Absorption

That burning coal particles in a typical furnace emit three-quarters of the radiant heat, leaving one-quarter for non-luminous gas radiation, is shown by Mac Adams.[2] Direct absorption of heat from the burning fuel particles rather than indirect absorption after heating the products of combustion to higher temperatures in furnaces with insulated water walls, seems more conducive of economy. Mac Adams shows the following heat transfer rates in a typical example

	Btu/hr/sq ft	Per cent of Total
At 2500 F furnace temperature		
CO_2 and water vapor radiation	21,110	22.5
Powdered coal particles radiation at 0.555 emissivity	72,500	77.5
Total radiation	93,610	100

Since no radiation occurs from nitrogen, which comprises 80 per cent of the products of combustion, the practice of furnace water-wall insulation renders heat of combustion more difficult of absorption by causing it to become stored in gases that surrender it only by relatively ineffective convection heat transfer. At 2000 F and normal boiler-entrance conditions, radiant heat transfer rate is approximately 20 times that of convection transfer.

Thick layers of gases and thick clouds of burning coal particles are necessary for highest radiant heat transfer rates at any given temperature. Taking advantage of thick layers in the furnace by covering all wall space with bare heat-absorbing tubes seems most efficient. Radiant heating in nests of boiler tubes is low because of thin gas strata and absence of burning fuel particles.

Rating of Furnaces

Is "Btu per hr per cu ft" always a reliable index of furnace conditions? It truthfully indicates real-estate and building space requirements, but it falls far short of indicating the most vital of furnace characteristics, namely, hotness.

To illustrate the above, three typical furnaces of widely different sizes are compared below. They emphasize that Btu per hr per cu ft is a very poor measure of furnace temperatures and heat absorption rates, and therefore indicates little of value regarding ash behavior, maintenance of refractory and other furnace surfaces, and requisite boiler performance.

Furnace	Domestic oil burning	Average industrial boiler	Large central-station boiler
Cubic equivalent, ft	1	10	40
Volume, cu ft	1	1,000	64,000
Wall area, sq ft	6	600	9,600
Cu ft of volume per sq ft of wall area	0.16	1.6	6.7
Btu per hr	250,000	50,000,000	1,000,000,000
Relative input	1	200	4,000
Btu per hr per cu ft	250,000	50,000	15,000
But per hr per sq ft of wall area	40,000	50,000	100,000

Though the large furnace has by far the lowest Btu per hr per cu ft, it will be appreciably hotter because its heat-input rate per square foot of radiant-heat-absorbing area is twice that of the smaller furnaces. It is obvious that furnace volumes increase more rapidly with size than do wall areas upon which cooling surfaces are disposed.

Btu per hr per sq ft of radiant-heat-absorbing surface affords a good index of furnace conditions providing the surface is not insulated initially with refractory nor in operation with ash.

Furnace exit temperature (boiler inlet temperature) has been suggested as a desirable index of furnace conditions and rating. Considering that ash slagging troubles at the boiler inlet are of much importance, the more general use of this value seems desirable.

[2] *Heat Transmission*, pages 87 and 88.

Furnace Versatility

Most versatile of all power plant equipment, must be the modern furnace. Changeable coal markets require that it burn coals with important differences in volatile content and ash characteristics, at various loads, and without affecting the performance of other equipment. Ash-softening temperatures of American coals vary from 1900 F to over 3000 F. Actual average furnace temperatures at normal loads vary from 2000 F to about 2600 F, depending upon the amount of radiant heat absorbed from the furnace.

Flame temperatures, without any furnace radiant heat absorption and with normal excess air, would vary from 3000 F to 3500 F. After considering that average furnace temperatures actually vary almost linearly with load, one realizes the almost infinite number of temperature combinations causing acceptable or unsatisfactory ash conditions.

While coping with the ash problem, the furnace must deliver definite quantities of heat to the boiler and superheater, for it is largely responsible for costly variations in steam temperature. It must burn widely different kinds of fuel with low excess air, yet with little combustible loss. Only by a careful cost estimate of the multitude of operating and investment costs affected by furnace design can an intelligent selection of best furnace equipment for a given installation be made. To make this careful cost estimate reliable, much test data and many actual operating costs must be available from past experience.

Critical examination of power-plant economy will indicate that the furnace is the proper starting point of the economy search.

Port Washington Performance

Figures are now available showing the operating results for several months at the Port Washington Station of the Milwaukee Electric Railway and Light Company. They are believed to set a new record in steam station performance, especially during April.

The plant was cut in on the system for the first time on October 14, 1935. After a few preliminary runs, during which the operating force was trained and certain operating characteristics determined, it was found necessary to shut down and readjust the relation between the water wall and steam wall surfaces in the rear of the furnace, a thing that had been provided for in the design should the necessity arise. The plant was again put into service on November 22, 1935, and ran continuously without a shutdown until March 14, 1936, when it was shut down for its regular spring inspection. Everything was found to be in excellent condition except a few minor things which required attention. The inspection was completed and the station put back into service on March 24 and has run continuously since then except for week-ends.

The economy figures by months follow:

Item	Dec. 1935	1936 Jan.	Feb.	March	April
Plant Output, kwhr	31,884,000	34,332,071	34,023,498	23,488,326	30,537,658
Load factor, per cent	72.22	76.24	62.97	53.94	72.43
Btu per net kwhr	11,639	11,336	11,255	11,444	10,946
Btu per lb of coal consumed	13,163	12,976	12,878	12,825	13,130

The average Btu consumed per net kilowatt-hour for these five months was 11,320 and the average Btu content of the coal was 12,999 Btu per pound.

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Combustion Studies by Models

"Aerodynamics as a Basis of Modern Fuel Practice," is the title of a paper by P. O. Rosin read recently before the Coal Research Club (London) and reprinted in the May issue of *Fuel in Science and Practice*. Every combustion process consists of a combination of chemical reaction and aerodynamic flow, and, by means of models, the author has conducted an extensive series of investigations to determine the effect of relative motion between fuel, air and gas on the speed of combustion. His studies covered combustion of coal on the grate as well as that of pulverized coal.

Commenting upon the use of models for this purpose the author says: "The essential point about experiments with models lies in producing physical similarity between the plant and the model. With a model it is not sufficient to make a proportional reduction in size alone, and in that way to produce a similarity of form. The physical correspondence only remains true if the ratios of particular forces and properties to the geometrical measurements remain the same in their reciprocal effects, both on a large scale and in the model. These ratios are the mathematical and constructional starting point for every investigation with a model."

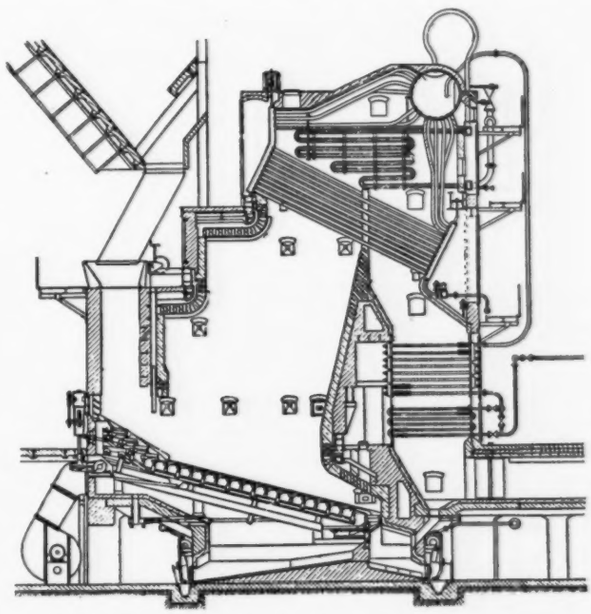
In investigating the burning of coal on a grate it was found that the intensity of combustion is conditioned by the formation of currents. For fuel beds that do not cake the dependence of combustion on the sizing of the coal, the dependence of the time for combustion on the average size of the particles and limits of size and the dependence of the time for combustion on the free surface of the grate were determined and the results are given. Inasmuch as combustion is always determined by the time required to burn the largest particles and not by the average, sizing plays an important part. A mixture of 8 to 10-mm size needs only 70 per cent of the time required by the same weight of 5 to 13-mm particles, although in each case the average size is the same. Moreover, if the particles are of approximately the same size, about 75 per cent of the solid combustible matter (neglecting volatile) is burned during the first half of the time required for combustion; whereas with a mixture of 5 to 20-mm size, 75 per cent of the weight is burned in 20 per cent of the total time. This means a very undesirable concentration of combustion at the beginning and the results are correspondingly poor.

With pulverized coal firing turbulence is of two kinds: first, interior turbulence—a property of the current itself—which is sufficient to accelerate combustion of the volatile matter but not the solid particles, and second, exterior or artificially produced turbulence. The latter may be produced by the detachment of eddies from solid surfaces and the formation of eddies by the friction of the gas streams, the first involving the aerodynamic problems of the burners and the second the technique of supplying combustion air. Entrance eddies have only a limited sphere of action and further turbulence must be set up by means of secondary and tertiary air which should be applied beyond the zone of the burner eddies.

Model photographs, diagrams and data are included in the paper in support of the author's contentions.

Setting for High-Moisture Fuel

The illustration shows an unusual furnace arrangement for burning low-grade coal containing 62 to 63½ per cent moisture in a German colliery as originally described in *Die Wärme* and reprinted in *Engineering and Boiler House Review* for May. The calorific value of this coal runs between 2880 and 3060 Btu per lb but the ash content is only 2 per cent. The fuel is introduced onto the steep front oscillating section of the stoker through a shaft extending the full width of the grate and the stoker is divided transversely into four sections each driven independently and supplied with its own blower.



Fuel is introduced on the front oscillating grate

As will be noted, a large furnace of 12,700 cu ft with a stepped front arch in addition to a rear arch, is employed. The boiler has 7000 sq ft of heating surface, the superheater 4090 sq ft, the steaming economizer section 16,100 sq ft and the cast-iron ribbed-tube economizer 11,600 sq ft. The steam pressure is 640-lb gage. On test with an output of 100,000 to 130,000 lb of steam per hour the unit showed efficiencies from 75.85 to 77.13 per cent.

Report on the Grid System

The eighth annual report of the Central Electricity Board (England) for 1935 showed an increase of 13.6 per cent in output over the preceding year. This covers 148 generating stations connected into the Grid and producing 95 per cent of the total electricity generated by the public utilities. Fifteen stations supplied more than half the output. The report estimates a saving in capital investment in generating capacity, attributable to the Grid system, equivalent to approximately 57 million dollars; while, due to the greater concentration in production by the most economical generating station, a yearly saving of about $4^1/_2$ million dollars was effected. *The Power and Works Engineer*, May 1936.

District Heating System Employs Electric Boiler

An interesting district heating installation at the Polytechnic Institute, Zurich, Switzerland, which supplies steam and hot water to twenty-one buildings within a half-mile radius is described in a recent issue of *Le Genie Civil*. The steam is extracted at 156 lb from the main turbine-generators and hot water at both 338 F and 176 F is supplied through heat exchangers receiving exhaust steam at 28 lb. The boiler plant contains one 1420-lb Sulzer single-circuit boiler, a 500-lb Sulzer multitubular boiler, a 500-lb Velox boiler and a smaller 156-lb Escher Wyss electric boiler. The high-pressure turbine exhausts at 500-lb pressure to two larger machines arranged for 156-lb steam extraction to the district steam main and exhausting at 28 lb to the heat exchangers which also receive exhaust steam from the auxiliaries. The summer heating load which is light is supplied by the electric boiler, the larger turbines being shut down during this period.

Germany to Standardize Steam Pressures and Temperatures

With a view to simplifying design and reducing boiler construction costs in Germany a committee of Verein Deutscher Ingenieure has been working with the German Standards Commission to standardize steam pressures. The following recommended design pressures (gage) for power boilers are reported in *Zeitschrift* for March 7, 1936.

Kg per sq cm	Equiv. lb per sq in.
250	3555
200	2844
160	2275
125	1778
100	1422
80	1138
64	910
50	711
40	569
32	445
25	356
20	284
16	228
13	185
10	142

The list also includes pressures for low-pressure boilers. The working pressure in the boiler drum is taken as 5 per cent under the design pressure and that at the superheater outlet 10 per cent lower.

Standard final steam temperatures are also proposed; these being as follows: 932 F, 887 F, 822 F, 777 F, 732 F, 687 F, 642 F, 597 F, 552 F and by increments of 45 deg down to 302 F.

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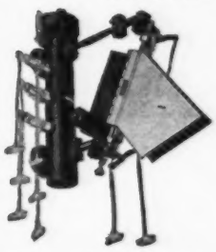

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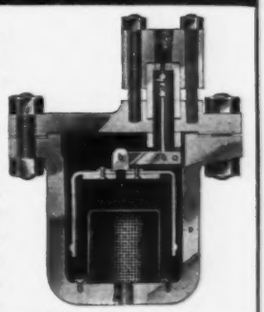

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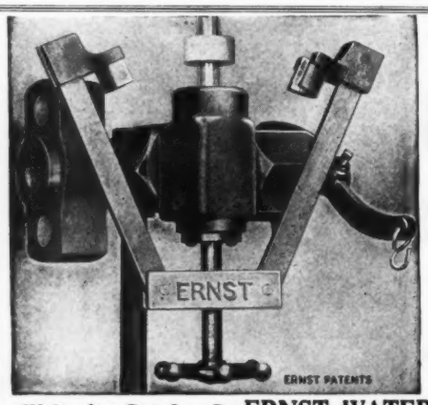

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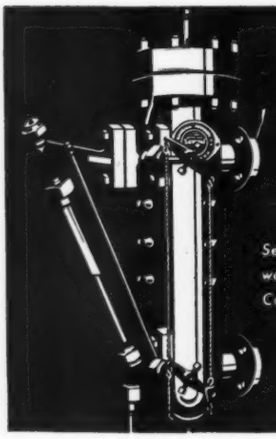

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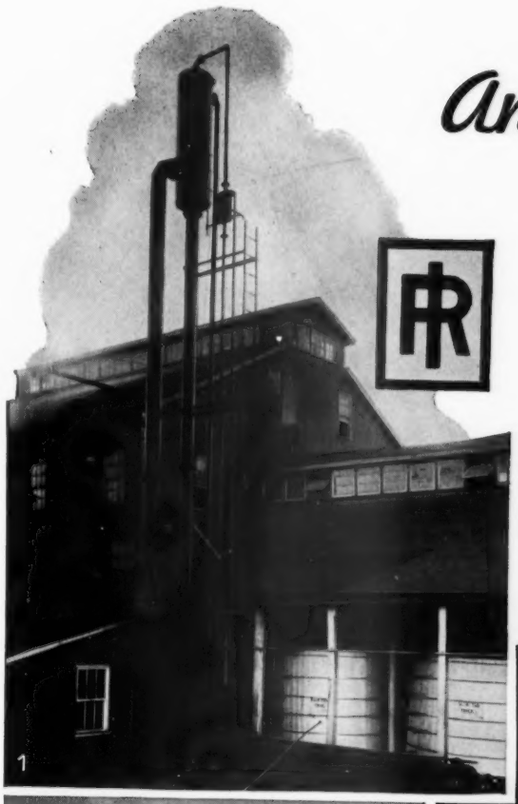
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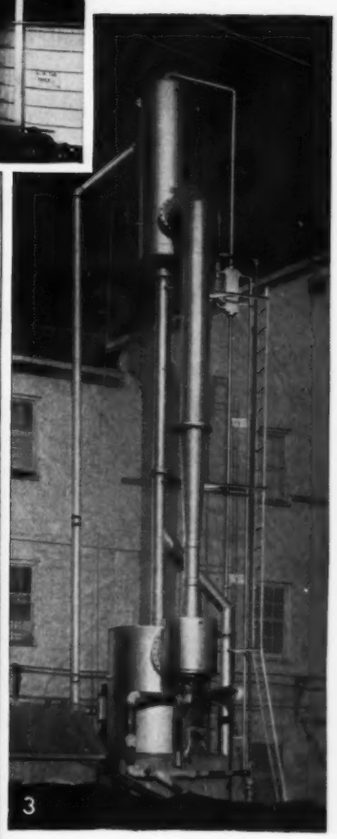
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